

Bulletin 27

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

TESTS OF COAL AND BRIQUETS

AS FUEL FOR

HOUSE-HEATING BOILERS

BY

D. T. RANDALL

ENGINE STORAGE

[Reprint of United States Geological Survey Bulletin 366]

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TESTS OF COAL AND BRIQUETS AS FUEL FOR HOUSE-HEATING BOILERS.

By D. T. RANDALL.

INTRODUCTION.

In carrying out a general plan of ascertaining more efficient and more economical methods of utilizing the fuel resources of the United States, in order to prevent unnecessary waste and thus conserve the available supply, the United States Geological Survey made a series of experiments on the combustion of fuel in house-heating boilers. As it was realized that steam boilers of the ordinary types used for heating private houses are often installed and operated under conditions unfavorable to fuel economy and smoke prevention, these experiments were made with briquets, raw coal, and washed coal, so as to determine what is to be expected of these fuels in a representative house-heating plant, properly installed and operated.

Briquetted coal had been frequently tested in the hand-fired furnaces under the Heine boilers in the Survey fuel-testing plant at St. Louis. The results were so satisfactory as regards economy and smokelessness that it was decided to conduct a series of tests to determine the value of this fuel for domestic heating purposes. Beginning in October, 1906, a number of evaporation tests were made on the house-heating boiler installed to heat the buildings occupied by the structural-materials laboratory, both briquets and coal being used. After these tests were well under way, it was thought advisable to conduct some additional tests under conditions more constant than could be maintained at this plant. A carload of briquets was shipped to the University of Illinois engineering experiment station at Urbana, Ill., where two house-heating boilers of a size commonly used in residences were available. This equipment permitted more uniform conditions of pressure and capacity, making the results more valuable for comparison. Tests were made with this fuel at Urbana in June and July, 1907. The present paper is an account of both series of tests, and includes also details of tests made at Urbana on three standard fuels in the spring of 1908.

Perhaps the most important result obtained is that showing the relative value of different fuels for domestic purposes. From Table 16. on page 39, it is possible by comparison to arrive at the probable value of any fuel in any part of the country. The figures in the table

show that with a sectional boiler the effectiveness of different fuels depends on the number of thermal units they contain. This means that if all fuels cost the same, the cheapest would be the one containing the largest number of thermal units. One basis for ascertaining the relative value of different fuels lies in the cost of evaporating 1,000 pounds of water. If, for example, at a certain place anthracite costs \$8 a ton and Pocahontas bituminous coal \$4, the cost of evaporating 1,000 pounds of water with anthracite would be 52 cents and with the bituminous coal 23.68 cents. This shows that a saving of about \$4 a ton for the same amount of work done would be effected by purchasing the bituminous coal.

The data obtained in the tests show that as the percentage of the rated capacity developed by the furnace increases the percentage of efficiency increases; also that high capacities were not obtained with the good coals, nor were the low capacities the result of burning poor coals.

A comparison of results on coal and on briquets shows no advantage in the briquets over coal of a size larger than screened nut. Briquetting good bituminous coal would be justified only when slack is used for material. The briquets tested gave much smoke, which was due to the pitch used as a binder.

The results indicate that coals containing the higher percentages of fixed carbon give the least smoke and are the most economical.

While these tests were going on a general inquiry was being made into the question of central heating plants. The results obtained in this inquiry, when compared with the results of the tests on house-heating boilers, show that such plants are economical for the householder and that they solve a part of the smoke problem in the cities. A brief summary of the results of this investigation is given on page 41.

All the results here recorded were calculated and checked by H. W. Weeks, who also compiled the tables and assisted in the preparation of this report. The observations on the tests at St. Louis were made by M. E. Baxter. The tests at Urbana were made under the direction of Prof. L. P. Breckenridge, director of the engineering experiment station and consulting engineer on steaming tests of the United States Geological Survey—the briquet tests by C. S. McGovney, assisted by A. B. Cook, Perry Barker, and S. B. Flagg, and the tests on standard fuels by J. M. Snodgrass.

FUELS TESTED.

At St. Louis 58 tests were made—11 with raw coal and 47 with briquetted coal having a binder of pitch.

At Urbana 24 tests on briquets were made—12 on each of the two boilers. In 18 of these tests round briquets manufactured on the Renfrow machine of the Geological Survey were used; the other

6 tests were conducted with square briquets made on the Survey's English machine. The square briquets were broken in half before firing. The percentage of pitch in the briquets ranged from 7 to 8.5. The briquets were manufactured at the fuel-testing plant. The round briquets were $3\frac{1}{8}$ inches in diameter and 2 inches thick, and the square briquets were $4\frac{1}{4}$ by $6\frac{3}{4}$ by $2\frac{1}{2}$ inches. Details of the manufacture are given in Table 1.

TABLE 1.—Coal and binders used in briquets tested at Urbana.

Coal.			Shape of briquet.	Binder. ^a			
Field designation.	Locality.	County.		Percentage used.	Flowing point.	Oils by distillation up to 743° F.	Extraction analysis: Pitch extracted (sample as received) by CS ₂ .
					° F.	Per ct.	Per cent.
Arkansas No. 13.....	Denning.....	Franklin.....	Round..	7	140.0	34.44	95.20
Illinois:							
No. 7 E.....	Near Collinsville..	Madison.....	do.....	8	143.6	25.76	96.90
No. 9 C.....	Near Staunton.....	Macoupin.....	do.....	9	143.6	25.76	96.90
No. 12 BW.....	Bush.....	Williamson.....	Square..	6.25	143.6	39.05	99.66
No. 29 A W.....	Livingston.....	Madison.....	Round..	7	143.6	39.05	99.66
No. 29 B.....	do.....	do.....	do.....	7	143.6	39.05	99.66
No. 30 W.....	Shiloh.....	St. Clair.....	do.....	8.5	143.6	25.76	96.90
No. 31.....	Warden.....	do.....	do.....	8	143.6	25.76	96.90
Do.....	do.....	do.....	Square..	7	161.6	28.98	89.31
No. 33.....	Trenton.....	Clinton.....	Round..	8	143.6	25.76	96.90
Indiana:							
No. 1 B.....	Mildred.....	Sullivan.....	do.....	8.5	161.6	28.98	89.31
No. 5 B.....	Hymera.....	do.....	do.....	9	143.6	25.76	96.90
No. 6 B.....	do.....	do.....	do.....	8.5	143.6	25.76	96.90
Do.....	do.....	do.....	Square..	7	143.6	25.76	96.90
Indian Territory:							
No. 2 B.....	Hartshorne.....	do.....	Round..	8	186.8	24.70	85.57
Do.....	do.....	do.....	Square..	8	172.4	20.00	99.60
Kansas:							
No. 2 B.....	Yale.....	Crawford.....	Round..	7	143.6	39.05	99.66
Do.....	do.....	do.....	Square..	7	143.6	39.05	99.66
Maryland No. 2.....	Frostburg.....	Allegheny.....	Round..	8	143.6	25.76	96.90
Missouri No. 10.....	Bevier.....	Macon.....	do.....	8	143.6	39.05	99.66
Pennsylvania:							
No. 18.....	Lloydell.....	Cambria.....	do.....	8	143.6	25.76	96.90
Do.....	do.....	do.....	Square..	7	143.6	25.76	96.90
No. 19.....	Hermine.....	Westmoreland.....	Round..	8	114.8	5.76	100.00
No. 20.....	Near Seward.....	do.....	Square..	6	143.6	25.76	96.50
No. 20 W.....	do.....	do.....	Square..	6	161.6	28.98	89.31
No. 22.....	Huff.....	do.....	Round..	8	161.6	28.98	89.31
Do.....	do.....	do.....	do.....	7	161.6	28.98	89.31
Do.....	do.....	do.....	Square..	6	161.6	28.98	89.31
Pennsylvania No. 15 (one-fourth).	Wehrum.....	Indiana.....	do.....	6	161.6	28.98	89.31
Rhode Island No. 1 (three-fourths).	Cranston.....	Providence.....	Round..	6.25	143.6	39.05	99.66
Pennsylvania No. 18 (one-fourth).	Lloydell.....	Cambria.....	do.....	8	143.6	25.76	96.90
Miscellaneous No. 9 (three-fourths).	do.....	do.....	do.....	8	143.6	25.76	96.90
Pennsylvania No. 18 (one-half).	Lloydell.....	Cambria.....	do.....	8	143.6	25.76	96.90
Rhode Island No. 1 (one-half).	Cranston.....	Providence.....	do.....	8	156.2	25.47	90.56
Pennsylvania No. 18 (three-fourths).	Lloydell.....	Cambria.....	do.....	8	143.6	25.76	96.90
Miscellaneous No. 9 (one-fourth).	do.....	do.....	do.....	8	143.6	25.76	96.90
Pennsylvania No. 18 (one-half).	Lloydell.....	Cambria.....	do.....	8	143.6	25.76	96.90
Miscellaneous No. 9 (one-half).	do.....	do.....	do.....	8	143.6	25.76	96.90
Virginia No. 5 B.....	10 miles west of Blacksburg.	Montgomery.....	do.....	7	143.6	39.05	99.66

^a Water-gas pitch except where otherwise noted.^b Wax tailings.

The chemical properties of these fuels are shown in Table 4 (pp. 25–31).

Several months after the briquet tests at Urbana 18 tests were made with the same boilers on three standard fuels—anthracite, coke, and Pocahontas bituminous coal. The results of these tests are also recorded in Table 4.

EQUIPMENT OF PLANTS.

ST. LOUIS PLANT.

The boiler on which the tests were made at St. Louis is a sectional steam boiler containing seven separate sections; it is 66 inches long and stands on a foundation 47 by 63 inches. The grate measures 36 by 54½ inches. The boiler has three 5-inch steam outlets at the

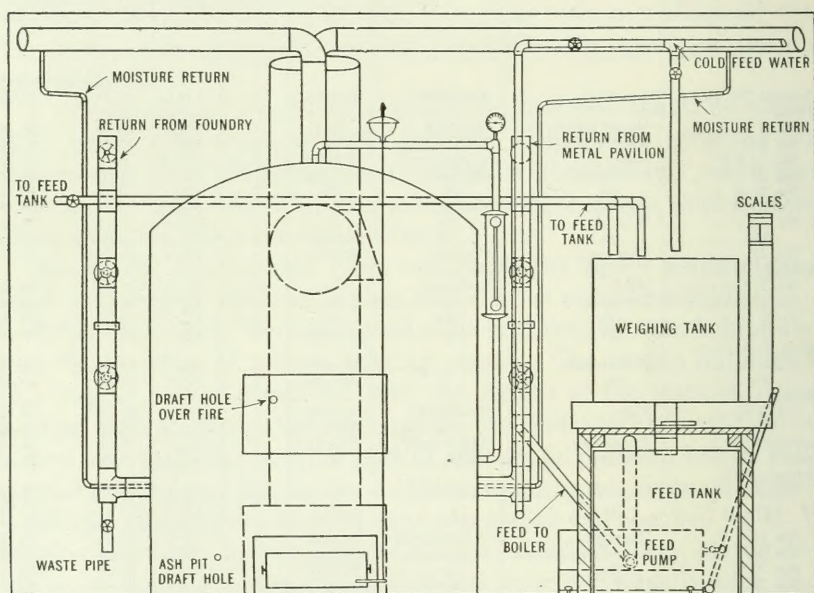


FIG. 1.—Elevation of house-heating boiler plant at St. Louis, Mo.

top of the sections, and is rated to take care of 3,150 square feet of radiating surface. The elevation and plan of the St. Louis plant are shown in figs. 1 and 2.

The boiler furnished steam to two buildings, supplying the necessary amount through two of the three outlets. The front outlet was not in use and was capped over. This boiler is made so that feed water may be supplied to every other section, entering at the base of the section on both sides, just above the grate level. There are six return inlets, but in this installation only the rear two were used. The piping was so arranged that during a test period all of the condensed steam was returned to the weigh tank, then allowed to discharge into a supply tank, from which it was forced into the boiler

by a hand pump. The temperature of the water entering the boiler ranged from 100° to 150° F., but usually averaged 140° . During a test all the water entered through one of the rear inlets.

In a sectional boiler as usually installed the steam as it is taken from the sections is first drawn into a collecting drum, so that in case of a sudden demand for steam, water will not be carried into the heating pipes. There was not enough head room for the installation of such a drum at the St. Louis plant, and the steam was drawn

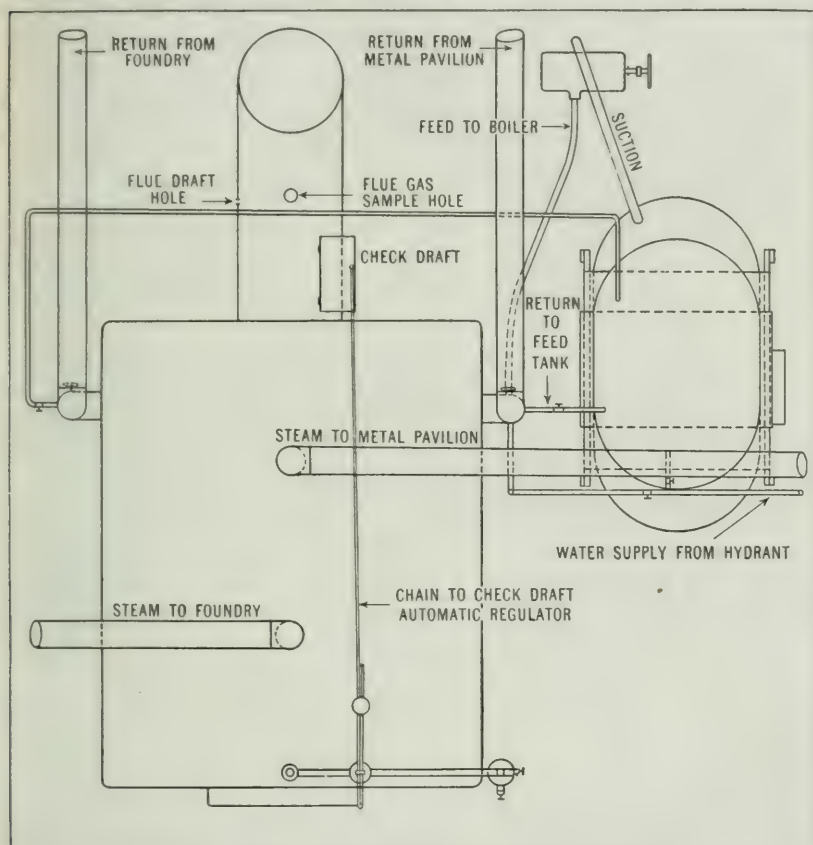


FIG. 2.—Plan of house-heating boiler plant at St. Louis, Mo.

directly from two sections. Drainpipes connected with the bottom of the steam pipes, as shown in fig. 1, carried moisture back to the boiler. No readings of moisture in the steam were taken, and therefore, in calculating water evaporated, the boiler was credited with slightly more work than it performed.

An automatic damper regulator was used to control the draft through the fire, so that a nearly constant steam pressure might be carried. This regulator was connected directly to the lower check and, by an arrangement of pulleys, to the check in the flue. All the exposed

surface of the boiler except the front was lagged with about an inch of plastic asbestos covering.

In the first 30 tests the draft was supplied by a stack 32.4 feet high above the grate. In these tests both natural and induced draft were used. In the last 28 tests the stack was raised to a height of 44.8 feet above the grate level. This height always furnished the required draft.

URBANA PLANT.

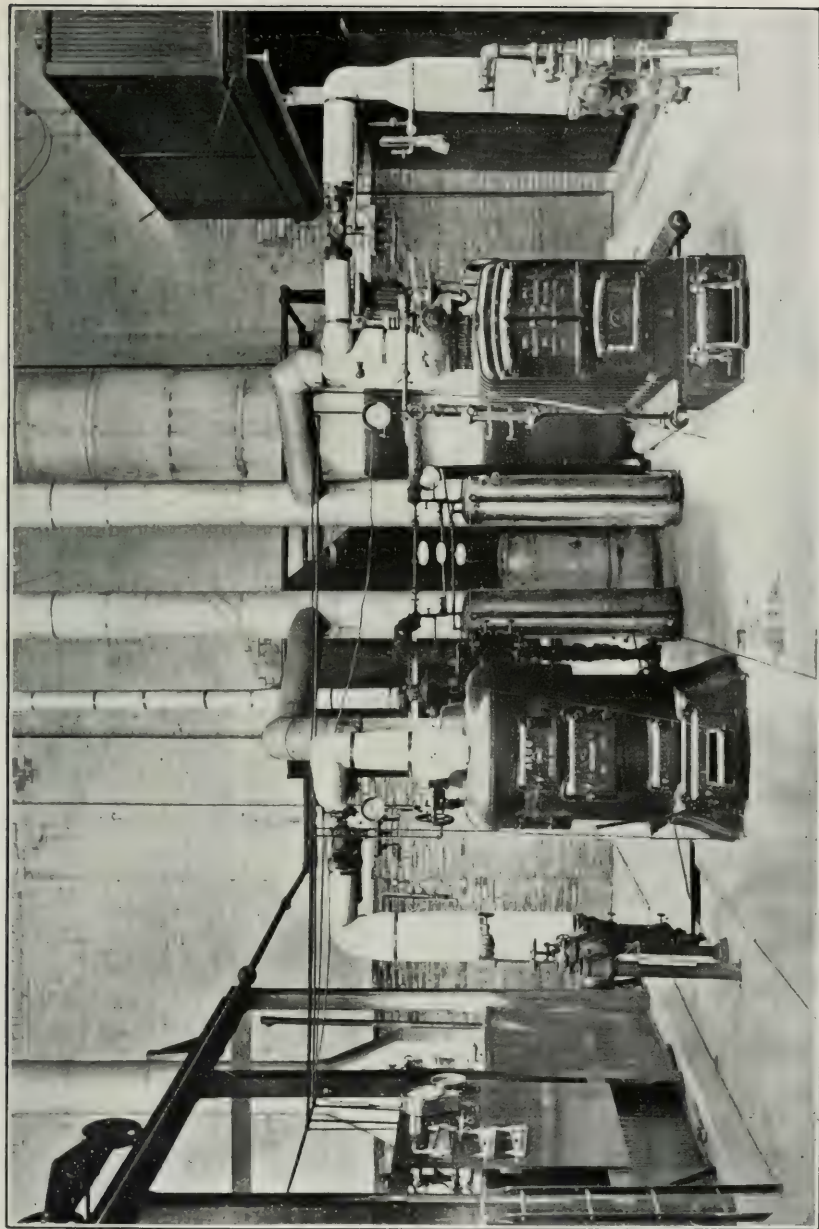
The two house-heating boilers in the experiment station at Urbana will be designated in this report as boiler A and boiler B. Both boilers are standard types supplied for use with either water or steam heating systems, except that in boilers of the type of boiler A a double section is usually substituted for the single intermediate section when used for water heating.

The general arrangement of the plant is shown in Pl. I. The boilers are set independently and each is provided with similar load regulators, return feed systems, and stacks. The flow is so arranged that the steam may be discharged to the atmosphere through an exhaust head above the roof of the building or into heating coils at the rear of the boilers. The coils contain 1,000 square feet of radiating surface, and are arranged in six sections, any number of which may be cut out and the amount of radiation changed in proportion. They constitute, with the overhead discharge pipes, the regular heating system of the experiment-station laboratory.

Boiler A is built up of four cast-iron sections—the base and grate section, the fire pot, the intermediate circulation section, and the dome. The water space surrounds the fire pot, and is continued into the intermediate and dome sections through three nipples. The principal dimensions and proportions of this boiler are given below:

Details of boiler A.

Rated capacity, radiating surface.....	square feet..	800
Height over all.....	feet..	5½
Floor space	square feet..	9
Size of fire door.....	inches..	8½ by 15
Height of fire door above grate.....	do....	14
Fuel capacity to center of fire door.....	pounds..	290
Kind of grate.....	Plain rocking.	
Width of grate.....	inches..	28
Length of grate.....	do....	28
Area of grate surface.....	square feet..	4. 28
Area of air space.....	do....	2. 15
Ratio of air space to grate surface.....	per cent..	50
Mean height of furnace.....	inches..	22. 5
Height of chimney above grate.....	feet..	39
Sectional area of chimney.....	square feet..	1. 07
Area of flue connecting to chimney.....	do....	0. 55
Length of flue connecting to chimney.....	feet..	14
Least flue area in boiler.....	square feet..	0. 67



HOUSE-HEATING BOILER PLANT AT URBANA, ILL.

Ratio of smallest flue area to grate surface.....	per cent..	15.5
Kind of draft.....	Natural.	
Direct water-heating surface.....	square feet..	18.8
Indirect water-heating surface.....	do....	20.7
Superheating surface.....	do....	4.2
Total heating surface.....	do....	43.7
Ratio of direct-heating surface to total.....	per cent..	43
Ratio of total heating surface to grate surface.....		10.2 to 1
Total water and steam space.....	cubic feet..	7.38
Steam space.....	do....	3.07
Water space.....	do....	4.31
Area of external boiler surface in contact with water or steam.....	square feet..	37.88
Smoke outlet above grate.....	feet..	4.17
Diameter of flue.....	inches..	14

Boiler B represents a common type of sectional construction in which the base or grate portion and the water-heating portion are built up of interchangeable cast-iron sections, the water legs or sections being connected by means of external circulation drums or headers. The following details apply to this boiler as now installed:

Details of boiler B.

Rated capacity, radiating surface.....	square feet..	1,075
Height over all.....	feet..	5½
Floor space.....	square feet..	25
Size of fire door.....	inches..	9 by 15
Height of fire door (bottom) above grate.....	do....	10
Fuel capacity to center of fire door.....	pounds..	370
Kind of grate.....	Patent rocker.	
Width of grate.....	inches..	18
Length of grate.....	do....	48
Area of grate surface.....	square feet..	6
Area of air space.....	do....	3
Ratio of air space to grate surface.....	per cent..	50
Mean height of furnace.....	inches..	22
Height of chimney above grate.....	feet..	39
Sectional area of chimney.....	square feet..	1.07
Area of flue connecting to chimney.....	do....	0.55
Length of flue connecting to chimney.....	feet..	12½
Least flue area in boiler.....	square feet..	0.495
Ratio of smallest flue area to grate surface.....	per cent..	8.23
Kind of draft.....	Natural.	
Direct water-heating surface.....	square feet..	21.89
Indirect water-heating surface.....	do....	53.98
Superheating surface.....	do....	None.
Total heating surface.....	do....	75.87
Ratio of direct-heating surface to total.....	per cent..	28.9
Ratio of total heating surface to grate surface.....		12.6 to 1
Total water and steam space.....	cubic feet..	11.16
Steam space.....	do....	3.28
Water space.....	do....	7.88
Area of external boiler surface in contact with water or steam.....	square feet..	103.27
Smoke outlet above grate.....	feet..	3
Diameter of flue.....	inches..	14

The equipment of these small boilers for experiments necessitated an especially devised method of supplying feed water and of controlling the load demand.

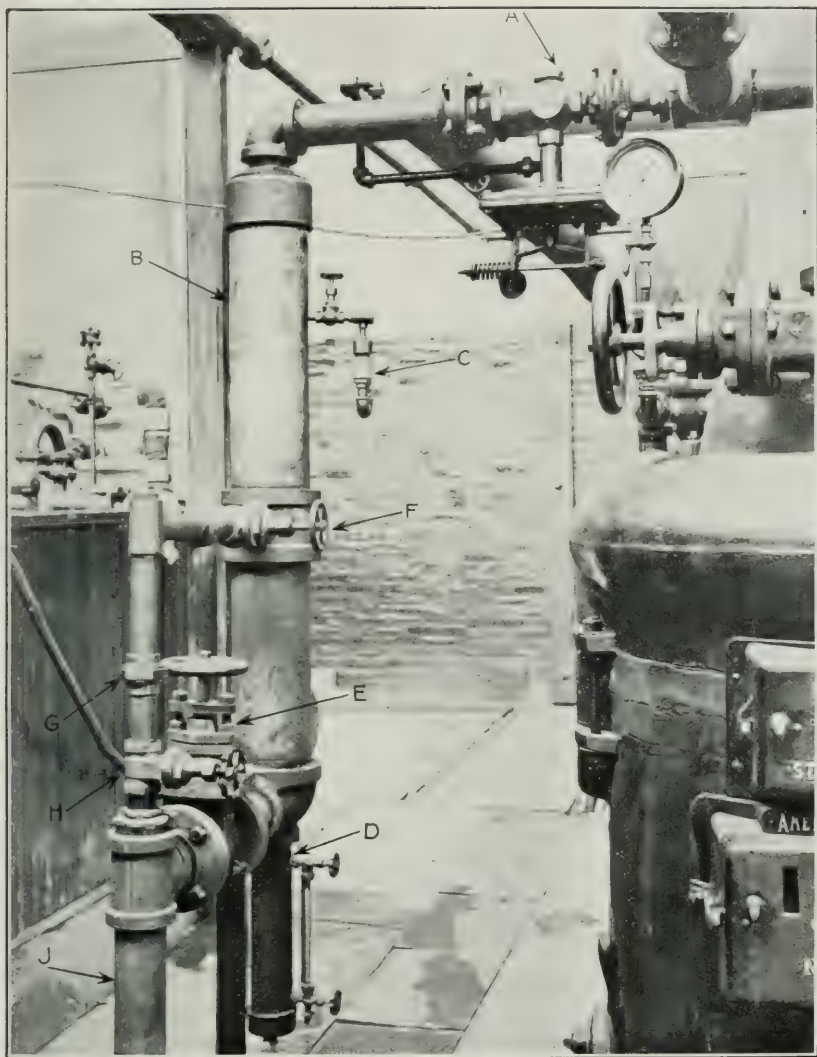
As the condensation return had to be intercepted for the purpose of weighing or measuring the feed water, the usual method of returning the condensed steam by gravity could not be used and other means had to be provided for forcing the water back into the boiler. A number of methods might have been used provided care was taken to insure steady feeding. The decision to adopt the system by which the feed water is forced from the measuring tanks into the boiler with compressed air was influenced to some degree by the temporary necessity of procuring condensation water from the heating coils. As all of the apparatus is located on the same level, this system has proved convenient and satisfactory.

The tanks used are ordinary galvanized-iron range tanks. One supply tank, with a capacity of 54 gallons, is connected directly in the return from the heating coils. The inlet pipe is at the bottom and the outlet at the top, so that the tank is always filled with hot water. The measuring tanks, or feed tanks, one for each boiler, have a capacity of 35 gallons each and are fitted with gage glasses and scales graduated to read pounds direct, correction being made for varying temperatures. An overflow pipe, with valve, placed at the top of the scale, allows filling the tank with a definite charge of water.

These tanks, as stated above, are connected with the compressed-air system and during feeding are under pressure sufficient to force the water into the boilers, a $\frac{1}{2}$ -inch needle valve near the boiler allowing close regulation of the feed. The heating system is under 3 to 5 pounds pressure, so that the measuring tanks are rapidly filled by simply opening a valve leading to the supply tank. The air pressure and boiler are cut off and the overflow is opened during charging.

Facility of controlling the rate of combustion is important when comparative studies of fuels are to be made. However, as these small heating boilers are designed to regulate themselves, under control of their automatic damper regulators, the rate of combustion may be kept fairly even by keeping the rate of evaporation constant. This has been accomplished at Urbana by the use of a pressure regulator, by which a steady flow of steam is discharged from a constant-pressure receiver through a suitable orifice into the atmosphere, provision being made for varying the load to suit the specific demand of the test. The receivers perform the duties of separators and are thus used to replace the usual steam calorimeter; for this reason the receivers and pipes are heavily lagged with 1 inch of hair felt laid next to the iron and above this 1 inch of magnesia pipe covering.

Pl. II shows one of the load regulators with its covering removed. The steam from the boiler passes through the pressure regu-



LOAD REGULATOR AT HOUSE-HEATING BOILER PLANT AT URBANA, ILL.

See text for explanation of reference letters.

later A into a 3-inch pipe which extends through the top of the receiver and nearly to the reducing tee at the bottom. Here the direction of the steam is changed and the entrained moisture separated, the dry steam passing up and out through the valve F to the exhaust main J, through an orifice plate in the 2-inch union G, the pipe J being open to the atmosphere. Pressure in the receiver is indicated by a mercury manometer at C, and another manometer (not shown) gives the back pressure in the pipe J, which is always under a slight pressure due to friction. The latter manometer is used to assist in adjusting the difference of pressure on the orifice. No attempt is made to compute the evaporation in this manner. The moisture separated from the steam collects in the 3-inch trap pipe D, the amount being indicated in pounds and fractions on the gage glass. Some moisture originally in the steam is of course evaporated in passing the reducing valve, consequently corrections of computed results for quality of steam and conversion to equivalent evaporation from and at 212° are made on the basis of the mean pressure maintained in the receiver—usually about 2 pounds.

Variation in load is obtained by the introduction of suitable orifices. The by-pass valve E allows changes to be made during operation, the orifices simply taking the place of a gasket in the union.

METHOD OF CONDUCTING TESTS.

TESTS AT ST. LOUIS.

The tests on the structural-materials laboratory boiler at St. Louis were made as nearly as possible under the actual running conditions of the average house-heating boiler plant. Steam was supplied to two buildings for heating, and consequently the load varied with the weather conditions—the temperature of the outside air and the velocity of the wind. On only a few of the tests was the heating load so light that steam was turned into the atmosphere.

Most of the tests covered a period of about eight hours; during this time the operator tried to maintain a steam pressure of about 3 pounds.

The alternate method, as prescribed by the American Society of Mechanical Engineers code for making boiler trials, was used in starting and stopping the tests. The boiler was installed in so small a room that the standard method of starting and stopping was not practicable. Each test was started with a fire about 4 inches thick. This thickness was gradually increased to a maximum of 12 to 18 inches, depending on the kind of coal burned and on the judgment of the operator as to the best thickness for good combustion. To start a test with a 4-inch fuel bed required that the boiler should be fired with the same kind of coal as was used on the test for about

four hours before beginning the test. In building up the fire and in burning it down for a close light firing was used. At other times during the tests the charges of coal were considerably greater. Coal was fired whenever the heat requirements demanded it, usually at a time when the fire had burned down and the steam pressure had dropped. The fresh coal was spread over the entire fuel bed. The fire seldom required any attention, and it was never poked unless a coal in burning caked badly. On the tests the fire was cleaned only just before starting and stopping, except in two or three tests when there was an unusually large accumulation of clinker upon the grate.

Readings were taken of draft, temperature, and steam pressure every thirty minutes. Smoke readings were taken as soon after coal was fired as other observations would permit, and at intervals thereafter until the volatile matter had distilled and no smoke was given off from the stack.

Owing to the many duties of the observer there was difficulty in procuring and analyzing representative samples of flue gas, but the results are considered of sufficient accuracy to indicate certain general relations between the air supply and the performance of the boiler. All gas samples analyzed showed some CO. This was to be expected, for the combustion was never complete on any of the tests, as could be seen by watching the top of the stack.

Smoke observations showed black smoke, comparable with the Ringelmann charts, at the times of firing and for several minutes afterwards, gradually turning to gray. This is of interest, owing to the fact that the gases resulting from the combustion of briquets at the Urbana station were as a rule of dirty yellowish color, and not comparable with the usual standards.

All briquets were fired whole. Shortly after they were fired the tar distilled and condensed on the boiler surface, forming a covering over the flue passages. When the fire was allowed to burn freely the coating on the flues ignited. In many tests this happened two or three times during an eight-hour run, and increased the temperature in the flue to a maximum of 1,500° F. On this account a thermocouple was used to take the temperature of the stack gases.

The flue passages were not brushed during the tests with briquets, as the burning of the tar effectually cleaned the boiler surfaces. In some tests the tar coating without doubt greatly lowered the efficiency of the boiler. It will be noted that the coal burned raw gave better results than when briquetted.

The furnace door was opened only at times of firing. On a few special briquet tests an attempt was made to reduce the smoke after firings by opening the slide draft in the furnace door, but either there was not enough air or it was admitted at the wrong point, for no

appreciable reduction of smoke resulted. No attempt was made to introduce air over the fire in the regular series of tests.

The analyses of the fuel burned and of the refuse were made at the chemical laboratory of the fuel-testing plant.

TESTS AT URBANA.

The plan for the tests at Urbana was as follows: (1) The load to be maintained between 60 and 70 per cent of the builders' rated capacity; (2) the load to be uniform throughout the test; (3) a steam pressure of 2 pounds to be carried on the heating system; (4) a definite charge of coal to be supplied at each firing; (5) each test to be of approximately eight hours' duration.

The standard method of starting and stopping the tests, as prescribed by the American Society of Mechanical Engineers, was used. A steam pressure of 5 pounds was maintained in the boiler for thirty to forty minutes before starting. At the start the ashes and the partly burned coal were rapidly removed and a weighed amount of wood was ignited; this operation required about three minutes, during which the steam pressure dropped from 5 pounds to 1 pound. As soon as the wood was lighted a signal was given to start the test and readings of time, water level, and pressures were taken. As soon as the wood was burning well a charge of about 25 pounds of coal was fired. In eight to ten minutes, when the coal was well ignited, the rest of a 75-pound car of coal was fired. The fire was not touched during the remainder of the test, except at times when the steam pressure fell below 5 pounds. When this occurred the fire was poked and raked and another 75-pound firing was made.

The following readings were taken every fifteen minutes: Height of water in boiler, height of water in tank, temperature of feed water, boiler-room temperature, steam pressure, pressure beyond reducing valve, back pressure in separator, height of water in separator, and drafts in ash pit, over the fire, and in the flue.

The air supply was taken entirely through the ash-pit door. On some of the tests it might have been advisable to admit a part of the air used for combustion continuously over the fire through the furnace door, or it might have been possible to increase the over-all efficiency of the boiler by admitting air over the fire for a few minutes after each firing by cracking the furnace door; but as such a procedure is not commercially practicable, no attempt was made to prove its effect.

As the duration of the trials was to be approximately eight hours, just enough coal was put on at the last firing to keep up 5 pounds steam pressure until time to close the test. When the steam pressure dropped below 5 pounds on the last firing, the grate was dumped and the unburned coal was rapidly placed in a can having a tight-fitting

cover which prevented further combustion. This unburned fuel removed at the close of the test, known as the residual fuel, was weighed separately from the ash that accumulated during the test. The ash and refuse from the coal were completely removed before the grates were dumped to clean them of the residual fuel. Just as the grates were dumped the final readings of time, water level, and pressures were taken.

The boiler flues were blown after the close of every test, so that the heat developed had an equal chance on the heating surface at the start of each test; however, on some of the trials more soot was formed than on others and the heating surface on these trials was therefore much less effective at the close than at the start.

The chemical analyses were made at the University of Illinois laboratory.

DATA AND RESULTS.

The principal items of the tables were calculated as indicated in the following formulas:

$$21.1. \text{ Coal} + 0.4 \times \text{wood}$$

$$21.2. \text{ Item 21.1} - \frac{\text{refuse} \times \text{per cent carbon} \times 14,600}{\text{item 46}}$$

$$23. \text{ Item 21.1} \times (100 - \text{moisture})$$

$$23.1. \text{ Item 23} - \frac{\text{refuse} \times \text{per cent carbon} \times 14,600}{\text{item 45}}$$

$$23.2. \text{ Item 23.1} - \frac{\text{ash} \times \text{per cent carbon} \times 14,600}{\text{item 45}}$$

$$43. \frac{\text{Item 23.1}}{\text{time}}$$

$$44. \frac{\text{Item 43}}{\text{grate}}$$

$$46. \text{ Item 45} \times (100 - \text{moisture})$$

$$47. \frac{\text{Separated water}}{\text{item 49}}$$

$$49. \text{ Water fed}$$

$$50. \text{ Item 49} \times \text{item 48}$$

$$51. \text{ From Kent's Pocket Book}$$

$$52. \text{ Item 50} \times \text{item 51}$$

$$53. \frac{\text{Item 52}}{\text{time}}$$

$$54. \frac{\text{Item 53}}{\text{heat surface}}$$

$$55. \frac{\text{Item 53}}{0.3}$$

$$55.1. \text{ Item 55} + \text{surface}$$

$$56. \frac{\text{Item 55}}{\text{rating}}$$

$$57. \frac{\text{Item 55}}{\text{item 21.2}}$$

$$58. \frac{\text{Item 52}}{\text{item 23.2}}$$

$$59. \frac{\text{Item 21.2} \times 100}{\text{time} \times \text{item 55}}$$

$$60. \frac{\text{Item 43} \times 100}{\text{item 55}}$$

$$61. \frac{\text{Item 58}}{\text{item 45}} \times 96,580$$

$$62. \frac{\text{Item 57}}{\text{item 46}} \times 96,580$$

$$64. \frac{\text{Item 63} \times \text{item 59}}{2,000} = \frac{\text{item 59}}{20}$$

$$65. \frac{\text{Item 63} \times 100}{2,000 \times \text{item 57}} = \frac{100}{2 \times \text{item 57}}$$

RESULTS AT ST. LOUIS.

The results of the tests at St. Louis are given in Table 2.

TABLE 2.—Tests of fuel in house-heating boiler at St. Louis.

Test No.	Designation of fuel.	Description of fuel.	Duration of trial (hours).	Average pressures.				
				Steam pressure in boiler (pasc.).	Barometer (pounds per square inch).	Draft (inch of water).		
						Between damper and boiler.	Over fire.	In ash pit.
			1	10	11.1	12	13	13.1
45	Arkansas No. 13.	Briquets, round.	8.33	2.2	14.39	0.34	0.07	0.04
58	Illinois No. 1.	Coal, run of mine.	7.92	1.9	14.36	.33	.07	.03
59	do.	do.	8.00	1.9	14.45	.36	.05	.03
48	Illinois No. 7 E.	Briquets, round.	8.00	1.7	14.45	.33	.06	.03
39	Illinois No. 9 C.	do.	8.30	1.7	14.54	.36	.07	.04
13	Illinois No. 12 BW.	Briquets, square, slack.	8.25	3.8	14.39	.21	.06	.05
52	Illinois No. 19 E.	Coal, egg.	7.80	2.4	14.56	.31	.03	.03
53	do.	do.	8.25	2.3	14.41	.35	.05	.04
54	do.	do.	8.06	2.1	14.30	.32	.03	.02
55	do.	do.	7.83	1.3	14.35	.36	.03	.02
9	Illinois No. 29 AW.	Briquets, round.	7.88	3.4	14.46	.24	.10	.06
12	Illinois No. 29 B.	Briquets, round, slack.	7.20	2.2	14.51	.23	.08	.07
33	Illinois No. 31.	Briquets, square.	7.83	2.7	14.37	.29	.13	.10
34	do.	do.	8.08	2.9	14.34	.28	.10	.06
44	do.	Briquets, round.	8.33	1.8	14.40	.36	.07	.04
43	Illinois No. 33.	do.	7.83	2.2	14.34	.32	.08	.05
37	Indiana No. 1 B.	do.	8.33	2.4	14.60	.35	.13	.07
36	Indiana No. 5 B.	do.	8.41	2.7	14.26	.34	.13	.08
38	Indiana No. 6 B.	Briquets, square.	7.88	2.8	14.64	.35	.09	.06
10	Indian Territory No. 2 BW.	Briquets, square, slack.	7.92	3.3	14.59	.25	.12	.08
11	Indian Territory No. 2 B.	Briquets, round, slack.	7.87	4.3	14.51	.22	.05	.04
1	Kansas No. 2 B.	do.	8.00	4.1	14.46	.22	.05	.03
40	do.	Briquets, square.	8.25	2.5	14.36	.36	.09	.06
21	Maryland No. 2.	Briquets, round.	8.00	2.9	14.65	.28	.12	.09
22	do.	do.	7.50	3.2	14.55	.23	.11	.10
23	do.	do.	8.00	3.6	14.51	.23	.11	.10
20	do.	Coal, run of mine.	7.88	2.2	14.52	.25	.13	.09
2	Missouri No. 10.	Briquets, round, slack.	7.66	3.4	14.68	.24	.04	.03
3	do.	do.	7.83	3.1	14.46	.21	.07	.05
4	do.	do.	7.82	3.2	14.54	.25	.08	.06
5	do.	do.	8.13	2.0	14.59	.26	.10	.05
28	Pennsylvania No. 18.	Briquets, round.	8.00	3.9	14.37	.18	.09	.08
29	do.	do.	8.00	4.6	14.44	.18	.07	.06
30	do.	Briquets, square.	7.70	3.3	14.51	.22	.11	.10
31	do.	do.	8.00	3.4	14.60	.29	.12	.10
46	do.	do.	8.13	2.1	14.40	.36	.03	.01
24	do.	Coal, run of mine.	8.00	3.0	14.55	.22	.10	.09
25	do.	do.	8.00	3.1	14.41	.22	.13	.09
32	Pennsylvania No. 19.	Briquets, round.	6.58	3.6	14.33	.27	.11	.07
15	do.	Coal, run of mine.	7.50	3.4	14.43	.23	.11	.10
26	Pennsylvania No. 20.	Briquets, square.	8.00	3.4	14.48	.23	.12	.09
27	do.	do.	8.00	3.3	14.40	.22	.11	.09
41	Pennsylvania No. 20 W.	Briquets, round.	7.81	3.3	14.30	.32	.07	.06
42	do.	do.	5.20	2.9	14.32	.33	.09	.08
16	Pennsylvania No. 22.	do.	7.83	3.7	14.46	.22	.11	.08
17	do.	do.	8.08	3.5	14.28	.21	.09	.08
18	do.	Briquets, square.	8.00	1.6	14.36	.23	.09	.07
19	do.	do.	8.05	2.4	14.36	.23	.12	.11
14	do.	Coal, run of mine.	7.58	3.8	14.55	.23	.10	.07
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).	Briquets, round.	8.23	2.0	14.51	.34	.07	.03
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths).	do.	8.16	1.6	14.38	.34	.04	.02
57	do.	do.	7.00	2.2	14.47	.36	.07	.04
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).	do.	5.66	3.2	14.31	.29	.10	.07
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth).	do.	8.23	3.0	14.45	.30	.06	.04
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half).	do.	7.83	2.2	14.40	.34	.07	.04
51	do.	do.	8.00	2.5	14.46	.33	.04	.02
7	Virginia No. 5 B.	do.	8.00	3.6	14.46	.24	.12	.10
8	do.	do.	7.80	4.8	14.35	.19	.09	.07

TABLE 2.—*Tests of fuel in house-heating boiler at St. Louis—Continued.*

Test No.	Designation of fuel.	Average temperatures (°F.).				Fuel as fired (pounds).	Dry fuel (pounds).	Total dry fuel fired minus dry fuel equivalent to the carbon in the ash (pounds).	Total ash and refuse from ash pit (pounds).
		External air.	Boiler room.	Feed water in weigh tank.	Gases escaping from boiler.				
		14	15	16	17	21	23	23.2	24
45	Arkansas No. 13.....	50	81	145	695	777	765	731	137
58	Illinois No. 1.....	64	88	121	710	854	739	706	151
59	do.....	46	73	126	720	874	756	728	128
48	Illinois No. 7 E.....	45	77	141	650	965	907	874	237
39	Illinois No. 9 C.....	58	83	137	855	871	824	789	195
13	Illinois No. 12 BW.....	69	92	143	.....	666	613	587	98
52	Illinois No. 19 E.....	59	85	138	600	817	757	727	114
53	do.....	66	88	128	720	927	859	827	122
54	do.....	62	85	135	635	811	752	725	104
55	do.....	72	93	123	850	764	708	685	87
9	Illinois No. 29 AW.....	31	70	149	.....	750	658	648	6
12	Illinois No. 29 B.....	46	79	147	.....	735	688	671	106
33	Illinois No. 31.....	80	91	106	570	813	738	725	112
34	do.....	82	96	101	400	836	759	743	139
44	do.....	51	82	138	795	968	901	880	144
43	Illinois No. 33.....	50	81	146	600	974	882	761	333
37	Indiana No. 1 B.....	57	91	120	815	1,104	1,056	1,037	120
36	Indiana No. 5 B.....	63	90	103	730	929	890	868	134
38	Indiana No. 6 B.....	45	82	140	715	815	768	750	144
10	Indian Territory No. 2 BW.....	33	71	150	.....	736	720	686	100
11	Indian Territory No. 2 B.....	42	76	158	.....	737	721	700	126
1	Kansas No. 2 B.....	40	72	145	.....	667	648	.....	113
49	do.....	48	84	135	665	800	772	743	172
21	Maryland No. 2.....	31	74	150	.....	652	628	612	73
22	do.....	30	80	146	.....	560	540	534	28
23	do.....	41	73	143	.....	650	626	611	7
20	do.....	32	71	144	.....	520	511	502	34
2	Missouri No. 10.....	32	70	151	.....	1,159	1,031	986	258
3	do.....	57	83	149	.....	769	684	651	189
4	do.....	27	69	139	.....	819	729	695	193
5	do.....	18	67	154	.....	1,036	922	898	136
28	Pennsylvania No. 18.....	46	81	140	.....	580	537	531	37
29	do.....	54	85	144	.....	652	604	598	34
30	do.....	42	83	146	.....	525	500	496	31
31	do.....	58	81	146	550	550	524	516	68
46	do.....	44	80	133	685	653	636	610	110
24	do.....	43	78	144	.....	550	539	527	47
25	do.....	42	74	145	.....	550	530	518	47
32	Pennsylvania No. 14.....	86	96	112	675	541	532	527	41
15	do.....	55	85	142	.....	456	447	438	27
26	Pennsylvania No. 20.....	44	77	145	.....	525	493	484	55
27	do.....	52	85	141	.....	550	516	508	48
41	Pennsylvania No. 20 W.....	48	84	146	570	594	587	577	56
42	do.....	45	76	134	620	388	383	374	53
16	Pennsylvania No. 22.....	48	78	141	.....	550	538	520	117
17	do.....	63	.....	158	.....	538	526	515	72
18	do.....	47	79	140	.....	553	533	503	92
19	do.....	46	77	140	.....	551	531	504	84
14	do.....	47	81	144	.....	492	483	459	97
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).....	45	77	147	605	652	647	616	112
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths).....	50	80	126	800	644	637	606	112
57	do.....	53	83	125	730	652	645	613	117
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).....	84	99	102	705	489	482	475	46
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth).....	47	79	142	550	648	636	609	130
50	Pennsylvania No. 18 (one-half) and miscellaneous No. 9 (one-half).....	47	80	140	630	646	638	596	133
51	do.....	49	79	139	620	651	643	598	142
7	Virginia No. 5 B.....	37	72	157	.....	712	680	639	154
8	do.....	45	77	155	.....	613	585	549	134

TABLE 2.—Tests of fuel in house-heating boiler at St. Louis—Continued.

Test No.	Designation of fuel.	Proximate analysis of fuel as fired (per cent).				Ultimate analysis of dry fuel (per cent).					
		Fixed carbon.	Volatile matter.	Moisture.	Ash.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
		26	27	28	29	30	31	32	33	34	35
45	Arkansas No. 13.....	68.30	15.11	1.49	15.10	75.05	3.84	1.81	1.35	2.62	15.33
58	Illinois No. 1.....	41.39	33.15	13.49	11.97	64.88	4.45	10.71	1.03	5.09	13.84
59	do.....	41.39	33.15	13.49	11.97	64.88	4.45	10.71	1.03	5.09	13.84
48	Illinois No. 7 E.....	40.34	30.09	6.06	23.51	59.48	3.54	5.70	.83	5.42	25.03
39	Illinois No. 9 C.....	47.63	33.55	5.43	13.39	68.44	4.44	8.30	.94	3.72	14.16
13	Illinois No. 12 BW.....	49.47	31.55	7.93	11.05	71.14	4.39	8.90	1.12	2.45	12.00
52	Illinois No. 19 E.....	51.22	31.00	7.33	10.45					2.76	
53	do.....	51.22	31.00	7.33	10.45					2.76	
54	do.....	51.22	31.00	7.33	10.45					2.76	
55	do.....	51.22	31.00	7.33	10.45					2.76	
9	Illinois No. 29 AW.....	43.99	37.16	12.29	6.56	72.22	4.92	10.25	1.07	4.06	7.48
12	Illinois No. 29 B.....	44.21	37.44	6.42	11.93	67.10	4.59	10.30	1.00	4.26	12.75
33	Illinois No. 31.....	43.90	33.03	9.17	13.90	66.14	4.33	8.93	1.01	4.29	15.30
34	do.....	43.90	33.03	9.17	13.90	66.14	4.33	8.93	1.01	4.29	15.30
44	do.....	42.85	35.21	6.98	14.96	66.75	4.85	7.33	.93	4.06	16.08
43	Illinois No. 33.....	40.75	28.25	9.47	21.53	60.07	3.93	9.47	1.03	1.72	23.78
37	Indiana No. 1 B.....	44.78	36.21	4.34	14.67	65.26	4.58	10.84	1.20	2.78	15.34
36	Indiana No. 5 C.....	48.91	35.74	4.20	11.15	70.47	4.85	7.53	.94	4.57	11.64
38	Indiana No. 6 B.....	43.16	37.83	5.72	13.29	66.48	4.76	8.42	1.07	5.17	14.10
10	Indian Territory No. 2 BW.....	51.51	35.86	2.19	7.44	75.69	4.84	8.76	1.53	1.57	7.61
11	Indian Territory No. 2 B.....	51.31	34.60	2.15	11.94	71.96	4.56	8.09	1.45	1.74	12.20
1	Kansas No. 2 B.....	46.78	31.67	2.78	18.77	63.00	4.35	4.90	.96	4.48	19.31
49	do.....	47.58	29.09	3.47	19.86	63.78	4.01	5.92	1.03	4.69	20.57
21	Maryland No. 2.....	68.54	21.14	3.63	6.69	82.41	4.74	3.40	1.62	.89	6.94
22	do.....	68.54	21.14	3.63	6.69	82.41	4.74	3.40	1.62	.89	6.94
23	do.....	68.54	21.14	3.63	6.69	82.41	4.74	3.40	1.62	.89	6.94
20	do.....	71.25	18.69	1.69	8.37					.92	
2	Missouri No. 10.....	38.67	32.24	11.03	18.06					4.18	
3	do.....	38.67	32.24	11.03	18.06					4.18	
4	do.....	38.67	32.24	11.03	18.06					4.18	
5	do.....	38.67	32.24	11.03	18.06					4.18	
28	Pennsylvania No. 18.....	64.61	19.45	7.43	8.51	80.80	4.44	2.88	1.16	1.53	9.19
29	do.....	64.61	19.45	7.43	8.51	80.80	4.44	2.88	1.16	1.53	9.19
30	do.....	69.14	18.43	4.71	7.72	81.77	4.40	3.22	1.26	1.25	8.10
31	do.....	69.14	18.43	4.71	7.72	81.77	4.40	3.22	1.26	1.25	8.10
35	do.....	62.80	24.23	2.55	10.42	78.65	4.36	3.38	.88	2.04	10.69
24	do.....	71.55	16.71	1.96	9.82					1.91	
25	do.....	71.88	16.46	3.56	8.10					1.76	
32	Pennsylvania No. 19.....	55.24	33.50	1.75	9.51	75.91	4.52	7.16	1.35	1.38	9.68
15	do.....	57.20	31.71	2.03	9.06					1.15	
26	Pennsylvania No. 20.....	64.38	19.23	6.16	10.23	78.13	4.20	2.83	1.09	2.85	10.90
27	do.....	64.38	19.23	6.16	10.23	78.13	4.20	2.83	1.09	2.85	10.90
41	Pennsylvania No. 20 W.....	67.74	20.58	1.23	10.45	79.20	4.56	1.52	1.12	3.02	10.58
42	do.....	67.74	20.58	1.23	10.45	79.20	4.56	1.52	1.12	3.02	10.58
16	Pennsylvania No. 22.....	55.12	32.11	2.21	10.56	75.72	4.52	6.41	1.39	1.16	10.80
17	do.....	55.12	32.11	2.21	10.56	75.72	4.52	6.41	1.39	1.16	10.80
18	do.....	54.27	30.57	3.55	11.61	75.93	4.58	5.10	1.24	1.11	12.04
19	do.....	54.27	30.57	3.55	11.61	75.93	4.58	5.10	1.24	1.11	12.04
14	do.....	57.96	29.45	1.77	10.82					.90	
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).....	69.71	15.96	.74	13.59	77.47	3.05	2.66	.49	2.64	13.69
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths).....	69.24	15.87	1.06	13.83	76.03	2.81	4.92	.81	1.45	13.98
57	do.....	69.24	15.87	1.06	13.83	76.03	2.81	4.92	.81	1.45	13.98
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).....	70.34	16.39	1.34	11.93	77.79	3.46	4.74	.53	1.39	12.09
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth).....	69.52	15.05	1.83	13.60	77.21	3.12	3.48	.70	1.64	13.85
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half).....	69.67	13.73	1.30	15.30	70.93	2.81	8.80	.75	1.21	15.50
51	do.....	69.67	13.73	1.30	15.30	70.93	2.81	8.80	.75	1.21	15.50
7	Virginia No. 5 B.....	65.93	14.28	4.52	15.27	76.18	3.67	2.52	.81	.83	15.99
8	do.....	65.93	14.28	4.52	15.27	76.18	3.67	2.52	.81	.83	15.99

TABLE 2.—*Tests of fuel in house-heating boiler at St. Louis—Continued.*

Test No.	Designation of fuel.	Analysis of ash and refuse (per cent).		Fuel per hour (pounds).				British thermal units per pound of fuel.	
		Carbon.	Earthy matter.	As fired.	Dry.	Burned per square foot of grate surface.		Dry.	As fired.
						As fired.	Dry.		
		37	38	43	43.1	44.1	44	45	46
45	Arkansas No. 13.....	22.06	77.94	93	92	6.89	6.81	13,112	12,917
58	Illinois No. 1.....	18.40	81.60	108	93	8.00	6.89	12,178	10,535
59	do.....	18.40	81.60	109	95	8.08	7.04	12,178	10,535
48	Illinois No. 7 E.....	10.02	89.98	121	113	8.96	8.37	10,667	10,021
39	Illinois No. 9 C.....	15.00	85.00	105	99	7.78	7.33	12,385	11,713
13	Illinois No. 12 BW.....	23.85	76.15	81	74	6.00	5.48	12,958	11,930
52	Illinois No. 19 E.....	22.05	77.95	105	97	7.78	7.18	12,411	11,501
53	do.....	22.05	77.95	112	104	8.30	7.70	12,411	11,501
54	do.....	22.05	77.95	101	93	7.48	6.89	12,411	11,501
55	do.....	22.05	77.95	98	90	7.26	6.67	12,411	11,501
9	Illinois No. 29 AW.....	13.95	86.05	95	84	7.04	6.22	13,306	11,671
12	Illinois No. 29 B.....	13.56	86.44	102	96	7.56	7.11	12,562	11,756
33	Illinois No. 31.....	9.47	90.53	104	94	7.70	6.96	12,024	10,921
34	do.....	9.47	90.53	103	94	7.63	6.96	12,024	10,921
44	do.....	11.97	88.03	116	108	8.59	8.00	11,995	11,158
43	Illinois No. 33.....	26.85	73.15	124	113	9.19	8.38	10,782	9,761
37	Indiana No. 1 B.....	13.13	86.87	133	127	9.86	9.41	11,907	11,390
36	Indiana No. 5 B.....	14.79	85.21	110	106	8.15	7.85	12,970	12,425
38	Indiana No. 6 B.....	10.48	89.52	103	97	7.63	7.18	12,557	11,839
10	Indian Territory No. 2 BW.....	32.11	67.89	93	91	6.89	6.74	13,865	13,561
11	Indian Territory No. 2 B.....	15.05	84.95	94	92	6.96	6.82	13,196	12,912
1	Kansas No. 2 B.....			83	81	6.15	6.00	12,132	11,795
40	do.....	13.53	86.47	97	94	7.18	6.96	11,855	11,444
21	Maryland No. 2.....	22.64	77.36	82	79	6.08	5.85	14,694	14,161
22	do.....	22.64	77.36	75	71	5.56	5.26	14,694	14,161
23	do.....	22.64	77.36	81	78	6.00	5.78	14,694	14,161
20	do.....	27.30	72.70	66	65	4.89	4.82	14,473	14,229
2	Missouri No. 10.....	13.89	86.11	151	135	11.20	10.00	11,588	10,310
3	do.....	13.89	86.11	98	87	7.26	6.44	11,588	10,310
4	do.....	13.89	86.11	105	93	7.78	6.89	11,588	10,310
5	do.....	13.89	86.11	127	113	9.41	8.37	11,588	10,310
28	Pennsylvania No. 18.....	16.64	83.36	73	67	5.41	4.97	14,408	13,338
29	do.....	16.64	83.36	82	76	6.07	5.63	14,408	13,338
30	do.....	12.02	87.98	68	65	5.04	4.81	14,559	13,873
31	do.....	12.02	87.98	69	66	5.11	4.89	14,559	13,873
46	do.....	22.54	77.46	80	78	5.93	5.78	14,038	13,680
24	do.....	25.38	74.62	69	67	5.11	4.97	14,096	13,200
25	do.....	25.38	74.62	69	66	5.11	4.89	14,377	13,865
32	Pennsylvania No. 19.....	10.44	89.56	82	81	6.08	6.00	13,889	13,646
15	do.....	31.05	68.95	61	60	4.52	4.44	13,996	13,712
26	Pennsylvania No. 20.....	15.53	84.47	66	62	4.89	4.59	14,064	13,198
27	do.....	15.53	84.47	69	65	5.11	4.82	14,064	13,198
41	Pennsylvania No. 20 W.....	17.04	82.96	76	75	5.63	5.56	14,069	13,896
42	do.....	17.04	82.96	75	74	5.56	5.48	14,069	13,896
16	Pennsylvania No. 22.....	15.01	84.99	70	69	5.18	5.11	13,867	13,561
17	do.....	15.01	84.99	67	65	4.96	4.82	13,867	13,561
18	do.....	30.83	69.17	69	67	5.11	4.96	13,764	13,275
19	do.....	30.83	69.17	68	66	5.04	4.89	13,764	13,275
14	do.....	22.96	77.04	65	64	4.82	4.74	13,812	13,568
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).....	24.55	75.45	79	79	5.85	5.85	12,887	12,793
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths).....	24.20	75.80	79	78	5.85	5.78	12,857	12,721
57	do.....	24.20	75.80	93	92	6.89	6.82	12,857	12,721
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).....	13.89	86.11	86	85	6.37	6.30	13,569	13,387
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth).....	19.30	80.70	79	77	5.85	5.70	13,431	13,185
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half).....	28.05	71.95	83	81	6.15	6.00	12,955	12,787
51	do.....	28.05	71.95	81	80	6.00	5.92	12,955	12,787
7	Virginia No. 5 B.....	24.07	75.93	89	85	6.59	6.30	13,136	12,542
8	do.....	24.07	75.93	79	75	5.87	5.56	13,136	12,542

TABLE 2. - *Tests of fuel in house-heating boiler at St. Louis—Continued.*

Test No.	Designation of fuel.	Water (pounds).		Factor of evaporation.	Equivalent evaporation per hour from and at 212° F. (pounds).	Horsepower developed.	Equivalent evaporation per hour from and at 212° F. per square foot of water heating surface (pounds).	Mean load carried (square feet of radiating surface).	Percentage of boiler's rated capacity developed.
		Fed to boiler.	Evaporated into dry steam from and at 212° F.						
				49	52	51	53	53.1	54	55	56
45	Arkansas No. 13.....	4,186	4,487	1.0720	539	15.6	3.39	1,797	57.0
58	Illinois No. 1.....	3,422	3,754	1.0970	474	13.7	2.98	1,580	50.2
59	do.....	3,809	4,159	1.0919	520	15.1	3.27	1,733	55.0
48	Illinois No. 7 E.....	3,708	3,989	1.0759	499	14.5	3.14	1,663	52.8
39	Illinois No. 9 C.....	3,786	4,089	1.0800	493	14.3	3.10	1,643	52.2
13	Illinois No. 12 BW.....	3,188	3,430	1.0758	416	12.1	2.62	1,387	44.0
52	Illinois No. 19 E.....	3,625	3,914	1.0798	502	14.6	3.16	1,673	53.1
53	do.....	4,482	4,886	1.0802	592	17.2	3.73	1,973	62.6
54	do.....	3,325	3,599	1.0825	447	13.0	2.81	1,490	47.3
55	do.....	3,959	4,334	1.0946	554	16.1	3.49	1,847	58.7
9	Illinois No. 29 A W.....	4,900	5,239	1.0692	665	19.3	4.18	2,217	70.4
12	Illinois No. 29 B.....	4,134	4,423	1.0700	615	17.8	3.87	2,050	65.1
33	Illinois No. 31.....	3,960	4,407	1.1130	563	16.3	3.54	1,877	59.6
34	do.....	4,292	4,801	1.1187	594	17.2	3.74	1,980	62.9
44	do.....	4,248	4,585	1.0794	550	15.9	3.46	1,833	58.2
43	Illinois No. 33.....	3,805	4,075	1.0710	521	15.1	3.28	1,737	55.2
37	Indiana No. 1 B.....	4,915	5,399	1.0985	648	18.8	4.08	2,160	68.6
36	Indiana No. 5 B.....	4,523	5,048	1.1161	600	17.4	3.77	2,000	63.5
38	Indiana No. 6 B.....	3,962	4,272	1.0782	542	15.7	3.41	1,807	57.4
10	Indian Territory No. 2 BW.....	4,866	5,198	1.0682	656	19.0	4.13	2,187	69.4
11	Indian Territory No. 2 B.....	5,411	5,739	1.0606	729	21.1	4.58	2,430	77.2
1	Kansas No. 2 B.....	3,433	3,686	1.0737	461	13.4	2.90	1,537	48.8
40	do.....	4,023	4,357	1.0829	528	15.3	3.32	1,760	55.9
21	Maryland No. 2.....	4,895	5,224	1.0673	653	18.9	4.11	2,177	69.1
22	do.....	4,188	4,489	1.0719	599	17.4	3.77	1,997	63.4
23	do.....	4,290	4,581	1.0754	573	16.6	3.60	1,910	60.6
20	do.....	4,079	4,377	1.0731	556	16.1	3.50	1,853	58.8
2	Missouri No. 10.....	5,152	5,498	1.0671	718	20.8	4.52	2,393	76.0
3	do.....	3,824	4,087	1.0688	522	15.1	3.28	1,740	55.2
4	do.....	4,036	4,356	1.0792	557	16.1	3.50	1,857	59.0
5	do.....	5,415	5,755	1.0627	708	20.5	4.45	2,360	74.9
28	Pennsylvania No. 18.....	3,720	4,014	1.0790	502	14.6	3.16	1,673	53.1
29	do.....	4,879	5,246	1.0752	656	19.0	4.13	2,187	69.4
30	do.....	4,404	4,722	1.0723	613	17.8	3.86	2,043	64.9
31	do.....	4,095	4,393	1.0728	549	15.9	3.45	1,830	58.1
46	do.....	4,343	4,710	1.0845	579	16.8	3.64	1,930	61.3
24	do.....	4,209	4,520	1.0740	565	16.4	3.55	1,883	59.8
25	do.....	4,113	4,413	1.0729	552	16.0	3.47	1,840	58.4
32	Pennsylvania No. 19.....	3,142	3,480	1.076	529	15.3	3.33	1,763	56.0
15	do.....	3,239	3,487	1.0765	465	13.5	2.92	1,550	49.2
26	Pennsylvania No. 20.....	4,069	4,367	1.0733	546	15.8	3.43	1,820	57.8
27	do.....	3,829	4,126	1.0775	516	15.0	3.25	1,720	54.6
41	Pennsylvania No. 20 W.....	4,416	4,735	1.0723	606	17.6	3.81	2,020	64.2
42	do.....	2,763	2,931	1.0844	564	16.3	3.55	1,880	59.7
16	Pennsylvania No. 22.....	3,473	3,743	1.0776	478	13.9	3.01	1,593	50.6
17	do.....	3,531	3,816	1.0807	472	13.7	2.97	1,573	49.9
18	do.....	3,457	3,723	1.0769	465	13.5	2.92	1,550	49.2
19	do.....	3,627	3,909	1.0777	486	14.1	3.06	1,620	51.4
14	do.....	3,844	4,132	1.0748	545	15.8	3.43	1,817	57.7
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).....	3,993	4,273	1.0700	519	15.0	3.26	1,730	54.9
56	Pennsylvania No. 18 (one-fourth) and miscellaneous No. 9 (three-fourths).....	4,173	4,555	1.0915	558	16.2	3.51	1,860	59.1
57	do.....	3,698	4,042	1.0929	577	16.7	3.63	1,923	61.0
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).....	3,118	3,485	1.1177	616	17.9	3.87	2,053	65.2
49	Pennsylvania No. 18 (three-fourths) and miscellaneous No. 9 (one-fourth).....	4,308	4,636	1.0761	563	16.3	3.54	1,877	59.6
50	Pennsylvania No. 18 (one-half) and miscellaneous No. 9 (one-half).....	3,890	4,158	1.0773	531	15.4	3.34	1,770	56.2
51	do.....	3,928	4,237	1.0787	530	15.4	3.33	1,767	56.1
7	Virginia No. 5 B.....	5,353	5,678	1.0608	710	20.6	4.47	2,367	75.1
8	do.....	4,270	4,544	1.0642	583	16.9	3.67	1,943	61.6

TABLE 2.—*Tests of fuel in house-heating boiler at St. Louis—Continued.*

Test No.	Designation of fuel.	Economic results (pounds).				Efficiency (per cent).	
		Equivalent evaporation from and at 212° F. per pound of fuel.		Fuel per hour per 100 square feet of radiating surface (mean load carried during test).		Boiler and furnace (dry fuel basis).	Plant (fuel as fired basis).
		As fired.	Dry.	As fired.	Dry.		
		57	58	59	60	61	62
45	Arkansas No. 13.....	5.77	6.14	5.18	5.12	45.22	43.14
58	Illinois No. 1.....	4.40	5.32	6.84	5.89	42.19	40.33
59	do.....	4.76	5.71	6.29	5.48	45.28	43.63
48	Illinois No. 7 E.....	4.13	4.56	7.28	6.80	41.28	39.80
39	Illinois No. 9 C.....	4.69	5.18	6.39	6.02	40.39	38.67
13	Illinois No. 12 BW.....	5.15	5.84	5.84	5.34	43.52	41.69
52	Illinois No. 19 E.....	4.79	5.39	6.28	5.80	41.94	40.22
53	do.....	5.27	5.91	5.68	5.27	45.99	44.25
54	do.....	4.44	4.97	6.78	6.24	38.67	37.28
55	do.....	5.67	6.33	5.30	4.87	49.25	47.61
9	Illinois No. 29 AW.....	6.98	8.08	4.29	3.79	58.64	57.75
12	Illinois No. 29 B.....	6.02	6.59	4.98	4.68	50.66	49.45
33	Illinois No. 31.....	5.42	6.08	5.54	5.00	48.83	47.93
34	do.....	5.74	6.46	5.20	4.75	51.88	50.76
44	do.....	4.74	5.21	6.33	5.89	41.94	41.02
43	Illinois No. 33.....	4.19	5.36	7.14	6.50	48.01	41.45
37	Indiana No. 1 B.....	4.89	5.21	6.16	5.88	42.25	41.46
36	Indiana No. 5 B.....	5.44	5.82	5.50	5.30	43.33	42.28
38	Indiana No. 6 B.....	5.24	5.70	5.70	5.37	43.84	42.74
10	Indian Territory No. 2 BW.....	7.06	7.58	4.25	4.16	52.79	50.28
11	Indian Territory No. 2 B.....	7.79	8.20	3.87	3.79	60.01	58.26
1	Kansas No. 2 B.....	5.53	5.69	5.40	5.27	45.29	45.28
40	do.....	5.45	5.86	5.51	5.34	47.74	45.99
21	Maryland No. 2.....	8.02	8.54	3.77	3.63	56.13	54.69
22	do.....	8.02	8.41	3.76	3.55	55.27	54.69
23	do.....	7.05	7.50	4.24	4.08	49.29	48.08
20	do.....	8.42	8.72	3.56	3.51	58.18	57.15
2	Missouri No. 10.....	4.75	5.58	6.31	5.64	46.50	44.49
3	do.....	5.31	6.28	5.63	5.00	52.34	49.74
4	do.....	5.32	6.27	5.66	5.01	52.25	49.83
5	do.....	5.55	6.41	5.38	4.79	53.42	51.98
28	Pennsylvania No. 18.....	6.92	7.56	4.37	4.01	50.67	50.10
29	do.....	8.05	8.78	3.75	3.48	58.85	58.28
30	do.....	9.00	9.52	3.33	3.18	63.15	62.65
31	do.....	7.99	8.52	3.77	3.61	56.51	55.62
46	do.....	7.21	7.72	4.14	4.04	52.71	50.90
24	do.....	8.22	8.58	3.67	3.56	58.78	57.44
25	do.....	8.02	8.52	3.75	3.59	57.23	55.86
32	Pennsylvania No. 19.....	6.43	6.60	4.65	4.60	45.89	45.50
15	do.....	7.64	7.96	3.94	3.87	54.92	53.81
26	Pennsylvania No. 20.....	8.32	9.02	3.63	3.41	61.94	60.88
42	do.....	7.50	8.12	4.01	3.78	55.76	54.88
27	Pennsylvania No. 20 W.....	7.97	8.21	3.76	3.71	56.35	55.39
41	do.....	7.56	7.84	3.99	3.94	53.81	52.54
16	Pennsylvania No. 22.....	6.81	7.20	4.40	4.33	50.14	48.50
17	do.....	7.10	7.41	4.26	4.13	51.60	50.56
18	do.....	6.74	7.41	4.45	4.32	51.99	49.03
19	do.....	7.09	7.76	4.20	4.07	54.45	51.58
14	do.....	8.40	9.00	3.58	3.52	62.93	59.79
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).....	6.55	6.94	4.57	4.57	52.01	49.44
56	Pennsylvania No. 18 (one-fourth) and miscellaneous No. 9 (three-fourths).....	7.08	7.52	4.25	4.19	56.48	53.75
57	do.....	6.20	6.60	4.84	4.79	49.57	47.07
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).....	7.13	7.34	4.19	4.14	52.24	51.43
49	Pennsylvania No. 18 (three-fourths) and miscellaneous No. 9 (one-fourth).....	7.16	7.61	4.21	4.10	54.72	52.44
50	Pennsylvania No. 18 (one-half) and miscellaneous No. 9 (one-half).....	6.44	6.98	4.69	4.57	52.03	48.64
51	do.....	6.51	7.09	4.59	4.53	52.85	49.16
7	Virginia No. 5 B.....	7.98	8.89	3.76	3.59	65.36	61.44
8	do.....	7.42	8.28	4.07	3.86	60.87	57.13

TABLE 2.—Tests of fuel in house-heating boiler at St. Louis—Continued.

Test No.	Designation of fuel.	Fuel at \$1 per 2,000 pounds.		Thickness of fire (inches).	Average amount of fuel fired at each firing (pounds/).	Average interval between firings (hours).	Clinkers in refuse (per cent).	Black smoke (per cent)
		Cost in cents per 100 square feet of radiating surface per hour (mean test carried during test).	Cost in cents of evaporating 1,000 pounds of water from and at 212° F.					
		64	65	69	70	71		77
45	Arkansas No. 13.....	0.2590	8.67	8-16	155	1.66	15	30.3
48	Illinois No. 1.....	.3420	11.36	8-14	171	1.58	38	25.7
49	do.....	.3150	10.50	8-16	175	1.60	38	41.2
48	Illinois No. 7 E.....	.3640	12.10		161	1.33	19	40.3
39	Illinois No. 9 C.....	.3200	10.65		145	1.36	28	32.6
13	Illinois No. 12 BW.....	.2420	9.71		74	.92	0	24.1
52	Illinois No. 19 E.....	.3140	10.44	4-12	163	1.56	0	37.1
53	do.....	.2840	9.49	8-16	155	1.37	20	30.3
54	do.....	.3390	11.25	8-16	162	1.61	21	32.5
55	do.....	.2650	8.82	6-14	153	1.56	0	31.5
9	Illinois No. 29 AW.....	.2150	7.16		62	.66	0	19.2
12	Illinois No. 29 B.....	.2490	8.31		67	.65	26	34.6
33	Illinois No. 31.....	.2770	9.23		163	1.56	13	22.7
34	do.....	.2600	8.71		167	1.61	24	23.7
44	do.....	.3170	10.55	8-16	161	1.39	46	29.1
43	Illinois No. 33.....	.3570	11.93	6-18	162	1.30	14	32.8
37	Indiana No. 1 B.....	.3080	10.22	4-16	158	1.19	48	28.5
36	Indiana No. 5 B.....	.2750	9.19	4-14	155	1.40	34	32.2
38	Indiana No. 6 B.....	.2850	9.54	8-14	163	1.58	47	32.3
10	Indian Territory No. 2 BW.....	.2130	7.08		74	.79	0	30.4
11	Indian Territory No. 2 B.....	.1940	6.42		67	.71	0	25.2
1	Kansas No. 2 B.....	.2700	9.04		56	.66	44	22.6
40	do.....	.2760	9.18	6-18	160	1.65	33	26.4
21	Maryland No. 2.....	.1890	6.24		93	1.14	0	14.4
22	do.....	.1880	6.24		140	1.32	0	
23	do.....	.2120	7.09		163	2.00	0	10.7
20	do.....	.1780	5.94		65	.98	0	1.4
2	Missouri No. 10.....	.3160	10.52		116	.77	29	41.6
3	do.....	.2820	9.42		55	.56	38	51.4
4	do.....	.2830	9.40		55	.52	29	30.6
5	do.....	.2690	9.01		65	.51	30	41.1
28	Pennsylvania No. 18.....	.2190	7.23		145	2.00	0	12.7
29	do.....	.1880	6.21		163	2.00	0	14.2
30	do.....	.1670	5.56		131	1.92	0	25.5
31	do.....	.1890	6.26	4-12	138	2.00	0	36.8
46	do.....	.2070	6.94		163	2.03	20	26.7
24	do.....	.1840	6.08		138	2.00	0	7.2
25	do.....	.1880	6.24		138	2.00	0	9.2
32	Pennsylvania No. 19.....	.2330	7.78		135	1.64	0	45.7
15	do.....	.1970	6.54		41	.68	0	14.2
26	Pennsylvania No. 20.....	.1820	6.01		131	2.00	0	16.6
27	do.....	.2010	6.67		138	2.00	0	17.7
41	Pennsylvania No. 20 W.....	.1880	6.27	4-16	148	1.96	0	29.7
42	do.....	.2000	6.61	6-18	129	1.73	0	
16	Pennsylvania No. 22.....	.2240	7.34		61	.87	0	25.1
17	do.....	.2130	7.04		60	.89	0	26.7
18	do.....	.2230	7.42		69	1.00	0	23.3
19	do.....	.2100	7.05		138	2.01	0	22.9
14	do.....	.1790	5.96		62	.95	0	16.1
47	Pennsylvania No. 15 (one-half) and Rhode Island No. 1 (one-half).....	.2290	7.64	4-18	163	2.06	24	29.9
56	Pennsylvania No. 18 (one-fourth) and Miscellaneous No. 9 (three-fourths).....	.2130	7.06	8-18	161	2.04	24	32.2
57	do.....	.2420	8.06	8-16	163	1.75	25	31.4
35	Pennsylvania No. 18 (one-half) and Rhode Island No. 1 (one-half).....	.2100	7.01	4-12	163	1.88	0	19.3
49	Pennsylvania No. 18 (three-fourths) and Miscellaneous No. 9 (one-fourth).....	.2110	6.98		162	2.06	16	
50	Pennsylvania No. 18 (one-half) and Miscellaneous No. 9 (one-half).....	.2350	7.77	8-16	162	1.96	0	28.9
51	do.....	.2300	7.68	10-18	163	2.00	0	32.6
7	Virginia No. 5 B.....	.1880	6.27		65	.73	0	16.7
8	do.....	.2040	6.74		123	1.56	0	39.5

Analyses of flue gas for CO_2 , O_2 , and CO were made with the following results:

TABLE 3.—Average percentage of CO_2 , O_2 , and CO from 53 tests made on fuel in house-heating boiler at St. Louis.

Test No.	CO_2 .	O_2 .	CO .	Test No.	CO_2 .	O_2 .	CO .
7	10.1	6.35	0.40	34	7.2	10.9	0.1
8	10.9	5.4	1.02	35	7.8	9.80	.10
9	10.22	7.56	1.7	36	7.9	8.3	.96
10	9.74	8.44	.34	37	12.1	4.3	.75
11	7.57	10.0	.68	38	9.3	6.8	.55
12	9.26	8.30	.44	39	8.75	5.45	1.0
13	6.96	11.35	.20	40	8.2	8.86	.53
14	7.0	10.68	.52	41	6.7	10.8	.20
15	5.8	11.30	.18	42	7.1	9.8	.25
16	6.8	11.3	.56	43	6.8	11.4	.4
17	6.8	10.26	.43	44	7.6	9.4	.4
18	7.2	9.85	.65	45	13.3	4.3	.6
19	8.0	8.77	.84	46	10.3	6.75	.65
20	7.13	9.83	.53	47	9.2	9.25	.15
21	8.6	7.25	.51	48	8.3	9.8	.6
22	8.0	6.58	1.62	49	8.1	9.80	.60
23	7.5	7.40	1.28	50	8.6	9.3	.15
24	6.8	11.84	.24	51	9.4	9.0	.60
25	7.0	11.60	.11	52	8.75	7.65	1.50
26	7.6	10.35	.28	53	9.8	6.65	1.0
27	5.8	12.81	.05	54	9.7	6.5	.6
28	7.5	10.75	.46	55	12.5	4.0	.75
29	7.4	10.76	.34	56	9.8	7.10	.40
30	7.4	10.63	.13	57	9.9	7.90	.25
31	6.5	10.40	.30	58	9.3	8.1	.45
32	7.0	10.35	.15	59	9.7	7.4	1.2

RESULTS AT URBANA.

The results of tests made at Urbana are given in the following table:

TABLE 4.—Tests of fuel in house-heating boilers at Urbana.

TESTS ON BRIQUETS.

Test No.	Boiler.	Designation of fuel.	Shape of briquets.	Date.	Duration of test (hours).	Average pressure.				Average temperature (° F.).		
						Steam (gauge).		Draft (inch of water).		External air.	Boiler room.	Feed water in weigh tank.
						Boiler.	Receiver.	Flue.	Over fire.			
					1	10	11	12	13	14	15	16
136	A	Illinois No. 7 E.....	Round..	June 19....	8.62	4.25	1.87	0.15	0.10			148.9
137	B	do.....	do.....	do.....	7.38	4.98	1.58	.16	.06			158.0
152	A	Illinois No. 9 C.....	do.....	June 28....	7.78	6.39	2.02	.15	.12	74	79	164.5
153	B	do.....	do.....	do.....	8.02	5.04	1.71	.15	.06	74	79	168.3
154	A	Illinois No. 30 W.....	do.....	June 29....	7.97	7.04	2.06	.15	.12	82	83	159.9
155	B	do.....	do.....	do.....	7.50	3.60	1.32	.13	.03	82	83	161.6
142	A	Illinois No. 31.....	do.....	June 22....	7.35	6.69	2.05	.15	.11			151.3
143	B	do.....	do.....	do.....	6.85	5.22	1.67	.15	.05			153.7
144	A	do.....	Square..	June 24....	7.93	5.61	1.94	.17	.10			150.8
145	B	do.....	do.....	do.....	7.52	6.02	1.70	.22	.04			144.5
158	A	Illinois No. 33.....	Round..	July 2.....	7.97	6.78	2.05	.15	.12	75	81	165.1
159	B	do.....	do.....	do.....	8.15	5.34	1.71	.18	.05	75	81	166.0
140	A	Indiana No. 1 B.....	do.....	June 21....	7.97	6.12	2.08	.15	.12			152.3
141	B	do.....	do.....	do.....	7.47	5.30	1.68	.18	.04			157.0
146	A	Indiana No. 6 B.....	do.....	June 25....	8.05	6.32	1.97	.15	.11	78	82	169.1
147	B	do.....	do.....	do.....	8.00	3.76	1.46	.19	.02	78	82	173.4
148	A	do.....	Square..	June 26....	8.08	6.59	2.07	.17	.13	77	83	155.8
149	B	do.....	do.....	do.....	8.25	5.44	1.74	.17	.05	77	83	156.6
138	A	Missouri No. 10.....	Round..	June 20....	7.95	5.63	1.97	.14	.10			163.1
139	B	do.....	do.....	do.....	7.67	4.44	1.86	.20	.05			162.7
156	A	Pennsylvania No. 20 W.....	do.....	July 1.....	9.17	6.11	2.00	.14	.12	83	88	167.2
157	B	do.....	do.....	do.....	8.02	5.30	1.60	.14	.07	83	88	169.7
150	A	Pennsylvania No. 22.....	Square..	June 27....	8.13	5.72	2.02	.18	.14	74	79	157.5
151	B	do.....	do.....	do.....	8.45	6.09	1.86	.15	.06	74	79	165.4

TESTS ON STANDARD FUELS.

162	A	Anthracite.....		Feb. 24....	8.77	6.0	2.0	0.13	0.10		83	173
163	B	do.....		do.....	8.00	4.5	2.0	.12	.05		82	175
166	A	do.....		Mar. 2, 3....	16.55	6.0	2.0	.15	.11		85	174
167	B	do.....		do.....	17.52	5.5	2.0	.08	.05		85	174
170	A	do.....		Mar. 9, 10....	24.05	6.5	2.0	.14	.11		79	175
186	A	do.....		May 4, 5....	23.15	7.0	2.0	.21	.12		76	180
187	B	do.....		do.....	26.00	5.0	2.0	.12	.07		76	179
178	A	Coke.....		Apr. 11....	8.43	7.0	2.0	.13	.08		69	168
180	A	do.....		Apr. 7.....	15.83	5.5	2.0	.12	.10		80	177
185	B	do.....		May 2.....	15.55	5.5	2.0	.10	.06		72	147
181	B	do.....		Apr. 7.....	14.92	5.5	2.0	.12	.07		80	174
182	A	do.....		Apr. 17, 18....	26.23	5.5	2.0	.10	.09		79	177
172	A	Pocahontas.....		Mar. 17....	10.07	6.0	2.0	.17	.12		84	165
173	B	do.....		do.....	12.65	5.0	2.0	.12	.09		83	157
174	A	do.....		Mar. 21, 22....	17.03	4.5	1.5	.16	.12		83	172
175	B	do.....		do.....	16.05	5.5	2.0	.13	.07		83	172
176	A	do.....		Mar. 23, 24....	25.13	5.5	2.0	.18	.13		80	177
177	B	do.....		do.....	25.93	5.5	2.0	.13	.08		80	174

TABLE 4.—*Tests of fuel in house-heating boilers at Urbana—Continued.*

TESTS ON BRIQUETS.

Test No.	Boiler	Designation of fuel.	Fuel as fired (pounds).				Dry fuel (pounds).			Total ash and refuse from ash pit (pounds).	Residual fuel removed (pounds).
			Wood.	Briquets.	Briquets plus wood.		Total fired.	Corrected for residual fuel.	Actually consumed (corrected for carbon in ash).		
					Corrected for residual fuel.	Corrected for residual fuel.					
			20	21	21.1	21.2	22	22.1	22.2	24	25
136	A	Indiana No. 7 E.....	8.0	27	35.4	34.9	247.3	27.4	274.7	34.0	32.5
137	B	do.....	8.0	27	35.4	34.9	247.3	27.4	274.7	34.0	32.5
138	A	Indiana No. 8 C.....	10.0	27	37.0	36.5	247.3	27.4	274.7	34.0	32.5
139	D	do.....	10.0	27	37.0	36.5	247.3	27.4	274.7	34.0	32.5
140	A	Indiana No. 9 F.....	10.0	27	37.0	36.5	247.3	27.4	274.7	34.0	32.5
141	B	do.....	10.0	27	37.0	36.5	247.3	27.4	274.7	34.0	32.5
142	A	Indiana No. 10.....	8.0	27	35.4	34.9	247.3	27.4	274.7	34.0	32.5
143	B	do.....	8.0	27	35.4	34.9	247.3	27.4	274.7	34.0	32.5
144	A	do.....	7.5	25	32.5	32.0	247.3	27.4	274.7	34.0	32.5
145	B	do.....	7.5	25	32.5	32.0	247.3	27.4	274.7	34.0	32.5
146	A	Indiana No. 11.....	10.0	28	38.0	37.5	247.3	27.4	274.7	34.0	32.5
147	B	do.....	10.0	28	38.0	37.5	247.3	27.4	274.7	34.0	32.5
148	A	Indiana No. 12 W.....	10.0	27	37.0	36.5	247.3	27.4	274.7	34.0	32.5
149	B	do.....	10.0	27	37.0	36.5	247.3	27.4	274.7	34.0	32.5
150	A	Indiana No. 13 O.....	10.0	24	34.0	33.5	247.3	27.4	274.7	34.0	32.5
151	B	do.....	10.0	24	34.0	33.5	247.3	27.4	274.7	34.0	32.5

TESTS ON STANDARD FUELS.

160	A	Anthracite.....	21	275	296	221	374	343	296	11	79
161	B	do.....	20	264	285	209	314	287	267	15	115
162	A	do.....	25	450	490	340	442	378	365	25	91
163	B	do.....	20	400	437	312	317	265	244	29	106
164	A	do.....	21	380	410	245	384	320	306	33	71
165	B	do.....	21	380	410	333	385	311	295	49	103
166	A	do.....	20	322	347	256	310	269	261	7	147
167	B	do.....	20	377	393	289	364	298	282	10	28
168	A	do.....	25	429	456	340	416	378	353	14	38
169	B	do.....	25	429	456	340	416	378	353	27	43
170	A	do.....	15	225	231	217	226	213	204	14	21
171	B	do.....	20	315	323	263	317	247	228	24	32
172	A	do.....	15	275	281	240	273	261	252	18	24
173	B	do.....	20	429	456	340	416	378	353	27	33
174	A	do.....	15	225	231	217	226	213	204	14	21
175	B	do.....	20	315	323	263	317	247	228	24	32
176	A	do.....	15	225	231	217	226	213	204	14	21
177	B	do.....	20	315	323	263	317	247	228	24	32

TABLE 4.—*Tests of fuel in house-heating boilers at Urbana—Continued.*

TESTS ON BRIQUETS.

Test No.	Boiler.	Designation of fuel.	Proximate analysis of fuel as fired (per cent). ^a				Ash in ultimate analysis of dry fuel (per cent).	Analysis of residual fuel (per cent).	
			Fixed carbon.	Volatile matter.	Moisture.	Ash.		Carbon.	Earthy matter.
			26	27	28	29	35	37	38
136	A	Illinois No. 7 E.			7.07		27.43	26.50	73.50
137	B	do.			7.07		27.43	35.34	64.66
152	A	Illinois No. 9 C.			6.89		14.60	35.87	64.13
153	B	do.			6.89		14.60	51.44	48.56
154	A	Illinois No. 30 W.			6.34		8.35	46.47	53.53
155	B	do.			6.34		8.35	71.34	28.66
142	A	Illinois No. 31.			9.53		16.81	40.71	59.29
143	B	do.			9.53		16.81	50.39	49.61
144	A	do.			8.46		16.76	46.16	53.84
145	B	do.			8.46		16.76	49.72	50.28
158	A	Illinois No. 33.			6.26		13.67	40.06	59.94
159	B	do.			6.26		13.67	53.09	46.91
140	A	Indiana No. 1 B.			6.80		14.11	50.81	49.19
141	B	do.			6.80		14.11	62.24	37.76
146	A	Indiana No. 6 B.			5.08		12.27	35.80	64.20
147	B	do.			5.08		12.27	63.04	36.96
148	A	do.			4.91		13.51	40.29	59.71
149	B	do.			4.91		13.51	53.58	46.42
138	A	Missouri No. 10.			6.56		21.57	51.85	48.15
139	B	do.			6.56		21.57	37.98	62.02
156	A	Pennsylvania No. 20 W.			3.16		7.98	85.21	14.79
157	B	do.			3.16		7.98	76.78	23.22
150	A	Pennsylvania No. 22.			3.61		9.68	74.34	25.66
151	B	do.			3.61		9.68	65.23	34.77

TESTS ON STANDARD FUELS.

162	A	Anthracite.	77.30	7.04	3.94	11.72		70.50	29.50
163	B	do.	77.30	7.04	3.94	11.72		76.65	23.35
166	A	do.	77.54	7.06	3.64	11.76		66.82	33.18
167	B	do.	77.54	7.06	3.64	11.76		70.18	29.82
170	A	do.	76.99	7.00	4.33	11.68		64.11	35.89
186	A	do.	79.85	4.27	4.13	11.75		65.01	34.99
187	B	do.	79.85	4.27	4.13	11.75		65.13	34.87
178	A	Coke.	81.35	2.78	6.12	9.75		46.71	53.29
180	A	do.	82.61	2.82	4.67	9.90		38.11	61.89
185	B	do.	85.20	1.73	3.71	9.36		47.17	52.83
181	B	do.	82.61	2.82	4.67	9.90		54.55	45.45
182	A	do.	80.79	2.76	6.76	9.69		54.06	45.94
172	A	Pocahontas.	73.36	19.50	1.97	5.17		65.71	34.29
173	B	do.	73.36	19.50	1.97	5.17		63.06	36.94
174	A	do.	73.32	19.49	2.02	5.17		50.36	49.64
175	B	do.	73.32	19.49	2.02	5.17		66.18	33.82
176	A	do.	73.32	19.49	2.02	5.17		37.15	62.85
177	B	do.	73.32	19.49	2.02	5.17		63.69	36.31

^a Moisture only determined except in standard tests.

TABLE 4.—*Tests of fuel in house-heating boilers at Urbana—Continued.*

TESTS ON BRIQUETS.

Test No.	Boiler.	Designation of fuel.	Ash (per cent).		Dry fuel per hour (pounds).		British thermal units per pound of fuel.		Moisture in steam (per cent.).
			Carbon.	Earthy matter.	Total.	Per square foot of grate surface.	Dry.	As fired.	
136	A	Illinois No. 7 E.....	18.30	81.70	36.72	8.58	10,142	9,425	1.02
137	B	do.....	21.47	78.53	40.13	6.69	10,142	9,425	.61
152	A	Illinois No. 9 C.....	8.23	91.77	31.84	7.43	11,845	11,029	.99
153	B	do.....	19.44	80.56	42.16	7.03	11,845	11,029	.90
154	A	Illinois No. 30 W.....	9.32	90.68	29.52	6.90	13,134	12,301	.82
155	B	do.....	22.77	77.23	35.03	5.84	13,134	12,301	1.11
142	A	Illinois No. 31.....	17.01	82.99	31.25	7.30	11,685	10,571	.83
143	B	do.....	19.50	80.50	35.56	5.93	11,685	10,571	.66
144	A	do.....	20.30	79.70	30.90	7.22	11,574	10,595	1.09
145	B	do.....	27.41	72.59	35.17	5.86	11,574	10,595	.72
158	A	Illinois No. 33.....	10.26	89.74	29.95	7.00	12,573	11,786	.95
159	B	do.....	12.38	87.62	37.58	6.26	12,573	11,786	.89
140	A	Indiana No. 1 B.....	25.57	74.43	31.43	7.34	12,379	11,537	.85
141	B	do.....	20.85	79.15	36.42	6.07	12,379	11,537	.69
146	A	Indiana No. 6 B.....	14.58	85.42	30.82	7.20	12,617	11,976	.90
147	B	do.....	13.47	86.53	37.81	6.30	12,617	11,976	.93
148	A	do.....	7.87	12.13	29.78	6.96	12,319	11,714	.76
149	B	do.....	14.94	85.06	37.61	6.27	12,319	11,714	.81
138	A	Missouri No. 10.....	21.87	78.13	33.21	7.76	11,012	10,290	.93
139	B	do.....	16.64	83.36	43.89	7.32	11,012	10,290	.65
156	A	Pennsylvania No. 20 W.....	28.87	71.13	22.67	5.30	14,262	13,811	.98
157	B	do.....	38.61	61.39	26.26	4.38	14,262	13,811	.78
150	A	Pennsylvania No. 22.....	23.17	76.83	24.79	5.79	13,646	13,153	1.08
151	B	do.....	27.70	72.30	28.80	4.80	13,646	13,153	.80

TESTS ON STANDARD FUELS.

162	A	Anthracite	46.07	53.93	24.2	5.65	13,216	12,698	0.96
163	B	do.	62.98	37.02	27.1	4.52	13,218	12,698	.68
166	A	do.	38.45	61.55	22.7	5.31	13,218	12,737	.93
167	B	do.	49.26	50.74	24.8	4.14	13,218	12,737	.61
170	A	do.	34.52	65.48	21.6	5.05	13,217	12,645	.94
189	A	do.	36.76	63.24	22.1	5.16	13,179	12,635	1.10
187	B	do.	44.78	55.22	23.5	3.92	13,179	12,635	.88
178	A	Coke	34.66	65.34	24.0	5.60	12,805	12,021	1.05
180	A	do.	18.89	81.11	22.0	5.10	12,804	12,206	1.04
185	B	do.	38.66	61.34	24.8	4.13	13,028	12,545	.82
181	B	do.	29.45	70.55	25.0	4.20	12,804	12,206	.78
182	A	do.	9.61	90.39	21.0	4.90	12,805	11,939	1.08
172	A	Pocahontas	67.91	32.09	21.1	4.93	15,055	14,751	1.00
173	B	do.	70.31	29.69	23.5	3.91	15,055	14,751	.69
174	A	do.	50.10	49.90	21.2	4.96	15,055	14,751	1.07
175	B	do.	66.53	33.47	24.8	4.13	15,055	14,751	.95
176	A	do.	57.11	42.89	23.2	5.42	15,055	14,751	1.03
177	B	do.	62.78	37.22	23.4	3.90	15,055	14,751	.77

TABLE 4.—*Tests of fuel in house-heating boilers at Urbana—Continued.*

TESTS ON BRIQUETS.

Test No.	Boiler.	Designation of fuel.	Factor for correction, quality of steam.	Water (pounds).			Factor of evaporation.	Water per hour (pounds).		Horsepower developed.
				Fed to boiler.	Corrected for quality of steam.			Equivalent evaporation from and at 212° F.	Equivalent evaporation from and at 212° F. per square foot of water-heating surface.	
					Corrected for quality of steam.	Evaporated into dry steam from and at 212° F.				
			48	49	50	52	51	53	54	
130	A	Illinois No. 7 E.....	0.9945	1.292	1.280	1.366	1.0677	158.5	2.48	4.50
131	B	do.....	.9943	1.306	1.377	1.457	1.0581	197.3	2.66	5.73
132	A	Illinois No. 9 C.....	.9907	1.216	1.204	1.266	1.0517	192.7	3.72	4.72
133	B	do.....	.9904	1.589	1.575	1.650	1.0477	205.8	2.80	5.65
134	A	Illinois No. 35 W.....	.9923	1.302	1.292	1.365	1.0566	171.3	3.40	4.97
135	B	do.....	.9895	1.234	1.221	1.287	1.0542	171.1	2.34	4.87
142	A	Illinois No. 31.....	.9923	1.147	1.138	1.212	1.0555	165.5	3.78	4.78
143	B	do.....	.9938	1.346	1.337	1.421	1.0626	207.5	2.83	5.02
144	A	do.....	.9906	1.228	1.210	1.256	1.0660	163.5	3.74	4.74
145	B	do.....	.9933	1.457	1.447	1.552	1.0722	206.7	2.82	5.09
138	A	Illinois No. 33.....	.9910	1.270	1.259	1.323	1.0612	196.9	3.80	4.81
139	B	do.....	.9909	1.515	1.502	1.577	1.0497	193.5	2.64	5.61
140	A	Indiana No. 1 B.....	.9920	1.216	1.206	1.285	1.0620	161.3	3.69	4.68
141	B	do.....	.9905	1.281	1.273	1.350	1.0592	188.7	2.47	5.14
146	A	Indiana No. 6 B.....	.9904	1.270	1.259	1.320	1.0469	194.4	3.75	4.76
147	B	do.....	.9911	1.420	1.407	1.496	1.0429	183.3	2.50	5.31
148	A	do.....	.9929	1.290	1.289	1.368	1.0609	199.2	2.87	4.91
149	B	do.....	.9923	1.609	1.605	1.754	1.0588	222.5	2.46	6.36
138	A	Missouri No. 10.....	.9912	1.243	1.232	1.297	1.0522	193.2	3.74	4.73
139	B	do.....	.9909	1.535	1.546	1.630	1.0594	212.5	2.90	6.16
136	A	Pennsylvania No. 20 W.....	.9907	1.377	1.364	1.431	1.0489	156.1	3.57	4.53
137	B	do.....	.9929	1.555	1.543	1.614	1.0460	201.6	2.74	5.84
150	A	Pennsylvania No. 22.....	.9899	1.264	1.251	1.325	1.0599	163.0	3.73	4.73
151	B	do.....	.9924	1.689	1.676	1.761	1.0606	208.4	2.84	6.04

TESTS ON STANDARD FUELS.

162	A	Anthracite.....	0.9911	1.348	1.336	1.393	1.0428	159	3.64	.....
163	B	do.....	.9907	1.377	1.367	1.431	1.0407	204	2.66	.....
166	A	do.....	.9914	2.318	2.496	2.601	1.0419	157	3.66	.....
167	B	do.....	.9944	3.432	3.413	3.556	1.0418	203	2.67	.....
170	A	do.....	.9913	3.700	3.698	3.817	1.0407	186	3.64	.....
180	A	do.....	.9898	3.568	3.532	3.658	1.0356	158	3.62	.....
187	B	do.....	.9918	4.990	4.919	5.099	1.0396	196	2.58	.....
178	A	Coke.....	.9904	1.387	1.374	1.440	1.0481	171	3.61	.....
180	A	do.....	.9904	2.393	2.370	2.462	1.0487	156	3.57	.....
185	B	do.....	.9929	3.612	3.600	3.199	1.0700	206	2.72	.....
181	B	do.....	.9928	2.954	2.934	3.057	1.0418	205	2.70	.....
182	A	do.....	.9900	4.047	4.037	4.162	1.0387	150	3.63	.....
172	A	Pecanontas.....	.9908	1.423	1.410	1.481	1.0501	147	3.36	.....
179	B	do.....	.9907	2.372	2.357	2.497	1.0505	197	2.66	.....
174	A	do.....	.9901	2.490	2.480	2.542	1.0435	149	3.41	.....
175	B	do.....	.9912	3.286	3.257	3.400	1.0439	212	2.79	.....
176	A	do.....	.9905	3.963	3.925	4.077	1.0387	192	3.71	.....
177	B	do.....	.9929	3.200	3.224	3.442	1.0418	210	2.77	.....

TABLE 4.—*Tests of fuel in house-heating boilers at Urbana—Continued.*

TESTS ON BRIQUETS.

Test No.	Boiler.	Designation of fuel.	Mean load carried.		Percentage of boiler's rated capacity developed (per cent).	Economic results (pounds).			
			Square feet of radiating surface.	Square feet of radiating surface plus radiating surface of boiler.		Equivalent evaporation from and at 212° F. per pound of fuel.		Fuel per hour per 100 square feet of radiating surface (mean load carried during test).	
						Fuel as fired.	Dry fuel consumed.	As fired.	Dry.
			55	55.1	56	57	58	59	60
136	A	Illinois No. 7 E.....	528	566	66.0	4.01	4.44	7.48	6.95
137	B	do.....	658	761	61.2	4.57	5.34	6.57	6.10
152	A	Illinois No. 9 C.....	542	580	67.8	4.76	5.16	6.31	5.87
153	B	do.....	686	789	63.8	4.55	5.06	6.60	6.15
154	A	Illinois No. 30 W.....	571	609	71.4	5.44	5.84	5.52	5.17
155	B	do.....	572	675	53.2	4.59	5.01	6.54	6.12
142	A	Illinois No. 31.....	550	588	68.8	4.77	5.41	6.28	5.68
143	B	do.....	692	795	64.3	5.28	6.11	5.68	5.14
144	A	do.....	545	583	68.2	4.84	5.49	6.19	5.67
145	B	do.....	689	792	64.1	5.37	6.22	5.58	5.10
158	A	Illinois No. 33.....	553	591	69.2	5.20	5.61	5.77	5.41
159	B	do.....	645	748	60.0	4.83	5.23	6.22	5.83
140	A	Indiana No. 1 B.....	538	576	67.2	4.78	5.34	6.27	5.85
141	B	do.....	602	706	56.0	4.63	5.16	6.49	6.05
146	A	Indiana No. 6 B.....	547	585	68.3	5.05	5.41	5.94	5.64
147	B	do.....	611	714	56.8	4.60	4.93	6.52	6.19
148	A	do.....	564	602	70.5	5.40	5.73	5.55	5.28
149	B	do.....	708	812	65.8	5.38	5.78	5.58	5.31
138	A	Missouri No. 10.....	544	582	68.0	4.59	5.24	6.53	6.10
139	B	do.....	708	812	65.9	4.53	5.05	6.63	6.20
156	A	Pennsylvania No. 20 W.....	520	558	65.0	6.67	7.06	4.50	4.36
157	B	do.....	671	774	62.4	7.42	7.99	4.04	3.91
150	A	Pennsylvania No. 22.....	543	581	67.9	6.33	6.74	4.73	4.56
151	B	do.....	695	798	64.6	6.97	7.46	4.30	4.15

TESTS ON STANDARD FUELS.

162	A	Anthracite.....	530	.....	66.3	6.30	6.76	4.75	4.56
163	B	do.....	680	.....	63.2	7.22	7.88	4.15	3.99
166	A	do.....	523	.....	65.4	6.67	7.13	4.51	4.34
167	B	do.....	677	.....	63.0	7.86	8.59	3.81	3.66
170	A	do.....	530	.....	66.3	7.03	7.54	4.26	4.08
186	A	do.....	527	.....	65.9	6.86	7.39	4.37	4.19
187	B	do.....	653	.....	60.7	8.02	8.69	3.75	3.60
178	A	Coke.....	570	.....	71.3	6.64	7.16	4.52	4.21
180	A	do.....	520	.....	65.0	6.73	7.12	4.45	4.23
185	B	do.....	687	.....	63.9	7.98	8.37	3.75	3.61
181	B	do.....	683	.....	63.5	7.72	8.19	3.89	3.66
182	A	do.....	530	.....	66.3	7.18	7.75	4.17	3.96
172	A	Pocahontas.....	490	.....	61.3	6.82	7.26	4.40	4.31
173	B	do.....	657	.....	61.1	8.24	8.98	3.65	3.58
174	A	do.....	497	.....	62.1	6.89	7.22	4.36	4.27
175	B	do.....	707	.....	65.8	8.37	9.02	3.58	3.51
176	A	do.....	540	.....	67.5	6.85	7.23	4.38	4.30
177	B	do.....	700	.....	65.1	8.76	9.37	3.42	3.34

TABLE 4.—*Tests of fuel in house-heating boilers at Urbana—Continued.*

TESTS ON BRIQUETS.

Test No.	Boiler.	Designation of fuel.	Efficiency. (per cent.).		Cost, in cents, per 100 square feet of radiating surface per hour (mean load carried during test). ^a	Cost, in cents, of evaporating 1,000 pounds of water from and at 212° F. ^a	Average amount of fuel fired at each firing (pounds).		Average interval (hours)—		Maximum interval of main- taining 2 pounds or more steam pressure without at- tention (hours).
			Boiler and furnace (dry fuel basis).	Plant (fuel as fired basis).			70	71	72	73	
136	A	Illinois No. 7 E.....	42.28	41.09	0.374	12.47	75	1.53	1.02	2.00	
137	B	do.....	50.85	46.83	.328	10.94	45	1.04	.76	1.77	
132	A	Illinois No. 9 C.....	42.07	41.69	.316	10.50	75	2.13	2.13	2.22	
133	B	do.....	41.26	39.84	.330	10.99	75	1.76	1.77	2.22	
134	A	Illinois No. 30 W.....	42.94	42.71	.276	9.19	75	2.40	2.40	2.55	
135	B	do.....	36.84	36.04	.327	10.89	75	1.74	1.74	2.37	
142	A	Illinois No. 31.....	44.72	43.58	.314	10.48	75	2.31	2.31	2.38	
143	B	do.....	50.50	48.24	.284	9.47	75	2.13	2.13	2.73	
144	A	do.....	45.81	44.12	.310	10.33	75	2.52	2.52	2.60	
145	B	do.....	51.90	48.95	.279	9.31	75	2.01	2.01	2.25	
138	A	Illinois No. 33.....	43.09	42.61	.289	9.62	75	2.61	2.61	2.83	
139	B	do.....	40.17	39.58	.311	10.35	75	1.91	1.91	2.62	
140	A	Indiana No. 1 B.....	41.66	40.02	.314	10.46	75	2.21	2.21	2.22	
141	B	do.....	40.26	38.76	.325	10.80	75	1.94	1.94	2.05	
146	A	Indiana No. 6 B.....	41.41	40.73	.297	9.90	75	2.54	2.54	3.03	
147	B	do.....	37.74	37.10	.326	10.87	75	1.89	1.89	2.48	
148	A	do.....	44.92	44.52	.278	9.26	75	2.73	2.81	3.62	
149	B	do.....	45.31	44.36	.279	9.29	75	2.14	2.14	1.83	
138	A	Missouri No. 10.....	45.96	43.08	.327	10.89	75	1.91	1.91	2.00	
139	B	do.....	44.29	42.52	.332	11.04	75	1.42	1.46	1.67	
156	A	Pennsylvania No. 20 W.....	47.81	46.64	.225	7.50	75	3.25	3.25	3.60	
157	B	do.....	54.11	51.89	.202	6.74	75	3.12	3.13	3.35	
150	A	Pennsylvania No. 22.....	47.70	46.48	.237	7.90	75	3.44	3.44	3.68	
151	B	do.....	52.80	51.18	.215	7.17	75	2.51	2.52	2.17	

TESTS ON STANDARD FUELS.

162	A	Anthracite.....	49.40	47.91	0.238	7.94	75	2.24	4.39	3.17	
163	B	do.....	57.58	54.91	.208	6.92	105	1.73	4.00	4.55	
166	A	do.....	52.10	50.58	.226	7.50	75	2.62	5.52	3.43	
167	B	do.....	62.76	59.60	.191	6.36	105	3.27	4.38	3.67	
170	A	do.....	55.09	53.69	.213	7.11	75	2.98	3.00	3.45	
186	A	do.....	54.16	52.43	.219	7.29	75	2.82	11.6	3.00	
187	B	do.....	63.68	61.30	.188	6.23	105	3.55	8.67	4.67	
178	A	Coke.....	54.00	53.34	.226	7.53	75	2.53	0	1.70	
180	A	do.....	53.71	53.25	.223	7.43	75	3.12	0	3.00	
185	B	do.....	62.50	61.44	.188	6.27	105	3.81	3.11	3.33	
181	B	do.....	61.77	61.08	.195	6.48	105	3.71	3.73	3.33	
182	A	do.....	58.45	58.08	.209	6.96	75	3.26	0	3.00	
172	A	Pocahontas.....	46.57	44.63	.220	7.33	75	2.95	1.26	1.87	
173	B	do.....	57.60	53.92	.183	6.07	105	3.53	1.05	2.63	
174	A	do.....	46.31	45.11	.218	7.26	75	3.08	.85	2.60	
175	B	do.....	57.86	54.80	.179	5.97	105	3.83	1.23	3.60	
176	A	do.....	46.38	44.84	.219	7.30	75	3.12	.74	1.20	
177	B	do.....	60.11	57.35	.171	5.71	105	4.24	1.13	2.82	

^a Based on fuel at \$1 per 2,000 pounds.

Table 5 shows the amount and character of soot formed on flues of boilers A and B as determined and recorded at end of test.

TABLE 5.—Amount and character of soot formed on flues of boilers A and B in briquet tests at Urbana.

Test No.	Boiler.	Soot measurements.	Test No.	Boiler.	Soot measurements.
136	A		140	A	Heavy; $\frac{1}{8}$ inch thick.
137	B		141	B	Heavy; $\frac{1}{8}$ to $\frac{1}{4}$ inch thick.
152	A	Heavy; $\frac{1}{16}$ to $\frac{1}{8}$ inch thick.	146	A	Heavy; large amount.
153	B	Do.	147	B	Large amount; choked draft entirely off.
154	A	Light and fluffy; $\frac{1}{8}$ inch thick.	148	A	$\frac{1}{16}$ to $\frac{1}{8}$ inch thick.
155	B	Light and fluffy; $\frac{1}{4}$ inch thick; choked draft entirely off.	149	B	Heavy; large amount.
142	A	Heavy.	138	A	Very little.
143	B	Do.	139	B	Do.
144	A	Do.	156	A	Fine and heavy; small amount.
145	B	Do.	157	B	Very little.
158	A	Very little.	150	A	$\frac{1}{16}$ inch thick or less.
159	B	Flaky; $\frac{1}{4}$ inch thick.	151	B	Do.

Owing to the fact that the character of the soot was so variable, it is difficult to draw any conclusion on comparative thickness deposited. Table 5 shows that there was a great variation in the amount formed. It is noticeable that in several of the tests a great deal of soot lodged in the flues, and that in two the flues were filled, choking the draft entirely. More difficulty was experienced with soot on boiler B than on boiler A.

The smoke observations for the tests made at Urbana are not reported in this table owing to the uncertainty as to their comparative accuracy. The readings were extremely difficult to make, owing largely to the peculiar color of the smoke. Smoke of about a shade between Ringelmann Nos. 1 and 2 (20 to 40 per cent black) from briquets made with pitch binder is of a dirty yellowish color, and though it is far more offensive than No. 4 smoke (80 per cent black) from raw or washed coal, it would probably be of about the same gravimetric density. In all the briquet tests the stack smoked badly for three-quarters of an hour after firing. About one hour after firing the stack became almost clean, remaining so until another charge was fired.

DEDUCTIONS FROM TEST DATA.

Table 6 is a compilation of nine different items from the St. Louis tests (exclusive of tests on mixed coals and one on Arkansas No. 13) averaged on the percentage of volatile matter in the combustible as a base. These results emphasize the difficulty of burning high-volatile coal in the fire pot of the average house-heating boiler, which has either inefficient or insufficient combustion space. The volatile matter varied over a wide range. The proximate analyses of fuel as fired showed that the lowest percentage of volatile matter was 14, in a Virginia coal, and the highest 38, in an Indiana coal. The efficiency

decreased regularly and decidedly as the volatile matter increased. The drop in efficiency was undoubtedly hastened by clinker formation, the percentage of clinker increasing with increase in sulphur values. Both the color and the analyses of the gases of combustion indicated lessening completeness of combustion as the percentage of volatile matter increased. The table shows that the volatile matter was neither an index of the CO_2 in the flue gas nor of the rated capacity developed, but this was to be expected, for each coal was made to carry the load required by weather conditions and was not burned at its highest possible rate of combustion.

TABLE 6. *Average of results from 50 tests, based on percentage of volatile matter in the combustible.*

Number of tests averaged.	Volatile matter in the combustible.	Sulphur in dry coal.	Ash in dry coal.	Efficiency.	Clinker.	Black smoke.	Percentage of rated capacity developed.	CO_2 in dry flue gases.	CO in dry flue gases.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per ct.</i>		<i>Per cent.</i>	<i>Per cent.</i>
4	18.30	1.33	8.00	60.56	0	18.2	63.7	8.7	0.44
12	22.71	1.74	8.94	56.33	0	18.0	61.1	7.3	.50
7	34.70	1.23	11.27	54.11	2.9	22.1	52.8	7.4	.55
11	38.79	2.64	15.02	47.19	12.0	30.8	57.1	8.7	.62
16	44.46	4.35	14.57	47.19	30.4	32.9	61.3	9.1	.74

Table 7 was derived by averaging the efficiency obtained in 52 of the St. Louis tests on the percentage of rated capacity developed as a base, the manner in which coals were grouped in getting the average points being shown in Table 8. A study of Table 7 shows that as the capacity increased the percentage of efficiency increased. The high capacities were not obtained with the good coals nor were the low capacities a result of burning poor coal. This relation of efficiency and capacity might be expected when it is remembered that to burn sufficient coal to develop high capacity the available draft must be used, giving more air for the combustion of the coal.

TABLE 7.—*Relation between percentage of rated capacity developed and efficiency.*

	Number of tests averaged for each point.	Percentage of rated capacity developed.	Efficiency.
			<i>Per cent.</i>
Group I.....	1	44	43.5
Group II.....	3	48	48.5
Group III.....	12	53	47.8
Group IV.....	20	58	52.5
Group V.....	9	64	53.3
Group VI.....	5	69	53.7
Group VII.....	2	76	62.7

TABLE 8.—*Grouping of coals in forming Table 7.*

	Test No.	Designation of fuel.		Test No.	Designation of fuel.
Group I.....	13	Illinois No. 12 BW.		32	Pennsylvania No. 19.
	54	Illinois No. 19 E.		26	Pennsylvania No. 20.
Group II.....	15	Pennsylvania No. 19.		42	Pennsylvania No. 20 W.
	18	Pennsylvania No. 22.		49	Pennsylvania No. 18 and
	58	Illinois No. 1.			Miscellaneous No. 9.
	59	Do.	Group IV—Con.	14	Pennsylvania No. 22.
	48	Illinois No. 7 E.		56	Pennsylvania No. 18 and
	39	Illinois No. 9 C.			Miscellaneous No. 9.
	52	Illinois No. 19 E.		57	Do.
	43	Illinois No. 33.		17	Pennsylvania No. 22.
Group III.....	28	Pennsylvania No. 18.		51	Pennsylvania No. 19 and
	27	Pennsylvania No. 20.			Miscellaneous No. 9.
	16	Pennsylvania No. 22.		53	Illinois No. 19 E.
	50	Pennsylvania No. 19 and		12	Illinois No. 29 B.
		Miscellaneous No. 9.		34	Illinois No. 31.
	19	Pennsylvania No. 22.		36	Indiana No. 5 B.
	47	Pennsylvania No. 15 and	Group V.....	22	Maryland No. 2.
		Rhode Island No. 1.		30	Pennsylvania.
	45	Arkansas No. 13.		41	Pennsylvania No. 20 W.
	55	Illinois No. 19 E.		35	Pennsylvania No. 18 and
	24	Pennsylvania No. 18.			Rhode Island No. 1.
	25	Do.		8	Virginia No. 5 B.
GROUP IV.....	44	Illinois No. 31.		9	Illinois No. 29 AW.
	38	Indiana No. 6 B.	Group VI.....	10	Indian Territory No. 2 B.
	40	Kansas No. 2 B.		21	Maryland No. 2.
	23	Maryland No. 2.		29	Pennsylvania No. 18.
	20	Do.	Group VII.....	37	Indiana No. 1 B.
	31	Pennsylvania No. 18.		11	Indian Territory No. 2 BW.
	46	Do.		7	Virginia No. 5 B.

When the boiler is run at low capacities the lower check draft is closed a large part of the time and, although this is effective in reducing the rate of combustion, the coal that burns is consumed with a very small air supply, resulting in a loss of combustible gases and making both the boiler and the furnace inefficient. Table 9, based on 52 of the St. Louis tests, shows the loss in efficiency when running with a diminished air supply. This table was obtained by averaging the percentage of CO in the flue gas and the efficiencies on the percentage of CO₂ in the flue gas as a base, the manner in which the coals were grouped to determine the average points being shown in Table 10. Table 9 shows that as the CO₂ increased the CO values became higher, but not with regularity, probably owing to differences in the character of the fuels. However, the low CO averages appear with the low CO₂ averages, and vice versa. This is sufficient proof that the combustion becomes less complete with a reduction of the air supply, resulting in higher values of CO₂. It is noticeable that at all times there was a harmful amount of CO present. The table demonstrates that with only one exception the boiler efficiency decreased with increase of CO₂, so that when the value of 13.3 per cent CO₂ had been reached the efficiency had dropped to 45.0, its lowest point. That high CO₂ in the flue gas is not necessarily an indication of high economy was pointed out in Bulletin 325.^a

^a A study of four hundred steaming tests: Bull. U. S. Geol. Survey No. 325, 1907, p. 27.

It is important to note that in the tests showing the lowest CO_2 the most air entered the furnace, the coal was more nearly burned, and the highest boiler efficiency was obtained. The table shows that the efficiency was higher with low CO values and accompanying excess of air than with reverse conditions. In all the tests there was not sufficient air used.

TABLE 9.—*Relation between CO_2 and CO in flue gas and efficiency.*

	Number of tests averaged.	CO_2 in flue gas.	CO in flue gas.	Boiler efficiency.
		Per cent.	Per cent.	Per cent.
Group I.....	2	5.8	0.12	55.3
Group II.....	6	6.7	.36	53.6
Group III.....	17	7.4	.12	53.4
Group IV.....	9	8.4	.82	49.3
Group V.....	11	9.6	.51	48.2
Group VI.....	4	10.4	.94	59.4
Group VII.....	2	12.3	.75	45.8
Group VIII.....	1	13.3	.60	45.2

TABLE 10.—*Grouping of coals in forming Table 9.*

	Test No.	Designation of fuel.		Test No.	Designation of fuel.
Group I.....	15	Pennsylvania No. 19.	Group IV.....	19	Pennsylvania No. 22.
	27	Pennsylvania No. 20.		49	Pennsylvania No. 18 and
	41	Pennsylvania No. 20 W.			Miscellaneous No. 9.
	16	Pennsylvania No. 22.		50	Pennsylvania No. 19 and
Group II.....	17	Do.			Miscellaneous No. 9.
	43	Illinois No. 33.		48	Illinois No. 7 E.
	31	Pennsylvania No. 18.		39	Illinois No. 9 C.
	24	Do.		52	Illinois No. 19 E.
Group III.....	42	Pennsylvania No. 20 W.		40	Kansas No. 2 B.
	18	Pennsylvania No. 22.		21	Maryland No. 2.
	14	Do.		22	Do.
	35	Pennsylvania No. 18 and		47	Pennsylvania No. 15 and
		Rhode Island No. 1.			Rhode Island No. 1.
	13	Illinois No. 12 BW.		56	Pennsylvania No. 18 and
	34	Illinois No. 31.			Miscellaneous No. 9.
	44	Do.		57	Do.
	36	Indiana No. 5 B.		51	Pennsylvania No. 19 and
	11	Indian Territory No. 2 BW.	Group V.....		Miscellaneous No. 9.
	23	Maryland No. 2.		58	Illinois No. 1.
	20	Do.		59	Do.
Group IV.....	28	Pennsylvania No. 18.		53	Illinois No. 19 E.
	29	Do.		54	Do.
	30	Do.		12	Illinois No. 29 B.
	25	Do.		38	Indiana No. 6 B.
	32	Pennsylvania No. 19.		10	Indian Territory No. 2 B.
	26	Pennsylvania No. 20.		7	Virginia No. 5 B.
			Group VI.....	8	Do.
				9	Illinois No. 29 AW.
Group V.....			Group VII.....	46	Pennsylvania No. 18.
				55	Illinois No. 19 E.
			Group VIII.....	37	Indiana No. 1 B.
				45	Arkansas No. 13.

Table 11 gives the average results of the tests at Urbana on three different kinds of standard fuel. Boiler B, a sectional boiler, shows a decided gain in efficiency when burning the same fuel over boiler A, a vertical boiler of the usual type. As the percentage of volatile matter in the combustible increases from 3.30 to 20.99, the efficiency of boiler A drops about 9 per cent, but that of boiler B drops only

about 3.5 per cent. This shows not only that boiler A is much less efficient than boiler B, but also that it is entirely unfitted for high-volatile coals.

TABLE 11.—Average results of tests on standard fuels at Urbana.

BOILER A.								
Kind of fuel.	Length of test (hours).	British thermal units per pound of dry fuel.	Efficiency (dry-fuel basis).	Cost of evaporating 1,000 pounds water from and at 212° F. (cents). ^a	CO ₂ in dry flue gases (per cent).	CO in dry flue gases (per cent).	Flue temperature (° F.).	Per cent of volatile matter in the combustible.
Coke.....	16.83	12,805	55.39	7.31	4.9	0.38	651	3.30
Anthracite.....	16.46	13,208	52.20	7.52	4.1	1.70	589	8.35
Pocahontas.....	17.41	15,055	46.42	7.30	5.1	.47	607	20.99

BOILER B.								
Kind of fuel.	Length of test (hours).	British thermal units per pound of dry fuel.	Efficiency (dry-fuel basis).	Cost of evaporating 1,000 pounds water from and at 212° F. (cents). ^a	CO ₂ in dry flue gases (per cent).	CO in dry flue gases (per cent).	Flue temperature (° F.).	Per cent of volatile matter in the combustible.
Coke.....	15.24	12,916	62.14	6.38	13.2	0.25	480	2.65
Anthracite.....	17.17	13,205	61.34	6.50	9.2	.66	519	7.26
Pocahontas.....	18.21	15,055	58.52	5.92	8.2	.35	520	20.99

^a Based on fuel at \$1 per 2,000 pounds.

Table 12, compiled from four tests made on an Illinois coal raw, three tests on an Illinois coal briquetted, and three tests on a Maryland coal briquetted, shows the relation between capacity and efficiency of the three fuels.

TABLE 12.—Relation between rated capacity developed and efficiency with three different fuels.

Designation of fuel.	Test No.	Percentage of rated capacity developed.	Efficiency.
			<i>Per cent.</i>
Illinois No. 19 E (raw coal).....	53	62.6	45.99
	55	58.7	49.25
	52	53.1	41.94
	54	47.3	38.67
Illinois No. 31 (briquets).....	34	62.9	51.88
	33	59.6	48.83
	44	58.2	41.94
Maryland No. 2 (briquets).....	21	69.1	56.13
	22	63.4	55.27
	23	60.6	49.29

Table 13 gives three heat balances on the house-heating boiler and one on a 210-horsepower hand-fired Heine boiler, determined at the fuel-testing plant at St. Louis. Test 39 was taken because it was a low-efficiency test with a high average flue-gas temperature; test 31 was a high-efficiency test with a low flue-gas temperature; and test 56 was a high-efficiency test with a high flue-gas temperature. The test on the high-pressure boiler was added for comparison of the

results obtained when burning coal in a small boiler and a reasonably large one. This test gave a higher efficiency than may be expected of the average commercial plant; it shows, however, what may be accomplished in the large plant as compared with the small one. The three loss items which differ the most are the loss up the stack, loss due to incomplete combustion of carbon, and radiation and unaccounted-for loss. These items must be higher on the house-heating boiler owing to the higher flue-gas temperature and poorer combustion. The high flue-gas temperature is due to inefficient heating surface, either poorly arranged or made inefficient by the soot and other products of incomplete combustion. Bulletins describing the work of the fuel-testing plant have called attention to the fact that the CO loss was indicative only of the true loss due to incomplete combustion and might not be nearly so large as the unknown loss. In the tests of Table 13, as the CO loss increases both the unaccounted-for loss and the loss up the stack increase; this corroborates former work of the Survey on high-pressure boilers and emphasizes the importance of constructing furnaces so that the fuel may be burned with a sufficient amount of air, properly distributed.

TABLE 13.—*Heat balances, or distribution of the heating values of the combustibles from boiler tests.*

Kind of boiler.....	House-heating.			Power plant.
Test No.....	39.	31.	56.	56.
Designation of sample.....	Ill. No. 9 C.	Pa. No. 18.	Pa. No. 18 and Misc. No. 9.	W. Va. No. 11.
Total heat value of 1 pound of combustible, British thermal unit.....	14,428.	15,842.	14,947.	15,934.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Heat absorbed by boiler.....	40.39	56.51	56.48	71.21
Loss due to—				
Moisture in coal.....	.65	.43	.11	.46
Moisture formed by burning of hydrogen....	4.53	3.43	2.72	3.24
Heat carried away in dry chimney gases....	25.91	22.82	24.93	19.37
Incomplete combustion of carbon.....	5.75	2.51	2.35	.33
Radiation unaccounted for.....	22.77	14.30	13.41	5.39
	100.00	100.00	100.00	100.00

Table 14 was derived by averaging the percentage of clinker in refuse and of black smoke on the percentage of CO₂ in flue gas as a base. Although it shows, with but one exception, that the CO₂ increases as the clinker in the refuse increases, the reader must not infer that the reduced air supply was entirely the result of clinker formation. It is true that when clinker forms on the grate there is more difficulty in drawing air through the fuel bed than when coal burns to a free ash; however, on these tests the lower check

draft was open only from a quarter to half the time, so that during the major portion of each test the coal was burned with reduced air supply. It is interesting to note from this table and from Table 6 that the smoke increased in density as the percentage of clinker in the refuse increased.

TABLE 14.—*Relation between CO₂ in flue gas, clinker in refuse, and smoke.*

Number of tests averaged for each point.	CO ₂ in flue gas.	Clinker in refuse.	Black smoke.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
2	5.8	0.0	16.0
6	6.7	2.3	26.4
16	7.4	6.5	20.6
8	8.4	12.0	25.3
11	9.6	24.0	32.1
4	10.4	5.0	25.5
2	12.3	24.0	30.0

Table 15, determined by averaging results on percentage of clinker in the refuse as a base, shows that the percentage of sulphur in dry coal followed closely the percentage of clinker in the refuse—that is, most of the low sulphur values were found in Group I and the high sulphur values in Groups V and VI.

TABLE 15.—*Relation between clinker in refuse, efficiency, and sulphur.*

	Number of tests averaged for each group.	Clinker in refuse.	Efficiency.	Sulphur in dry coal.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Group I.....	32	0	54.8	1.67
Group II.....	2	14	48.4	2.96
Group III.....	4	19	48.7	2.97
Group IV.....	9	26	48.7	3.21
Group V.....	6	35	47.4	4.63
Group VI.....	4	46	43.3	4.12

Table 16 gives the relative values of several fuels for heating purposes. The results were obtained by evaporative tests on house-heating boilers of the two different types—sectional and vertical. These tests were made at Urbana on boilers A and B. The chemical analysis, British thermal unit determination, and efficiency of the boiler are given for each fuel. The figures under relative fuel values show that with a sectional boiler the effectiveness of different fuels is in proportion to the number of thermal units they contain; thus, if all fuels were sold at the same price the cheapest would be the one containing the largest number of thermal units.

TABLE 16. --Relative values of fuels for use in house-heating boilers.

Kind of fuel.	No. of tests made.	Coal as fired.					Efficiency of boiler and grate.
		Moisture.	Volatile matter.	Fixed carbon.	Ash.	British thermal units.	
SECTIONAL BOILER.							
Pocahontas.....	3	<i>Per ct.</i> 2.00	<i>Per ct.</i> 19.49	<i>Per ct.</i> 73.33	<i>Per ct.</i> 5.17	14,753	<i>Per ct.</i> 55
Maryland.....	1	1.69	18.69	71.25	8.37	14,229	57
Pennsylvania.....	2	2.75	16.58	71.71	8.96	13,842	57
Do.....	2	1.90	30.58	57.58	9.94	13,640	57
Coke.....	2	4.19	2.28	83.91	9.63	12,376	61
Anthracite.....	3	3.90	6.12	78.23	11.74	12,690	59
Illinois.....	4	7.33	31.00	51.22	10.45	11,501	42
Do.....	2	13.49	33.15	41.39	11.97	10,535	42
VERTICAL BOILER.							
Coke.....	3	5.85	2.79	81.58	9.78	12,055	55
Pocahontas.....	3	2.00	19.49	73.33	5.17	14,753	45
Anthracite.....	3	4.01	6.33	77.92	11.73	12,679	51

Cost (in cents) of evaporating 1,000 pounds of water from and at 212° F. with price of fuel ranging from \$1 to \$10 per ton of 2,000 pounds.

Kind of fuel.	\$1.	\$2.	\$3.	\$4.	\$5.	\$6.	\$7.	\$8.	\$9.	\$10.
SECTIONAL BOILER.										
Pocahontas.....	5.92	11.84	17.76	23.68	29.60	35.52	41.44	47.36	53.28	59.20
Maryland.....	5.94	11.88	17.82	23.76	29.70	35.65	41.58	47.52	53.46	59.40
Pennsylvania.....	6.16	12.32	18.48	24.64	30.80	36.96	43.12	49.28	55.44	61.60
Do.....	6.25	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50
Coke.....	6.38	12.76	19.14	25.52	31.90	38.28	44.56	51.04	57.42	63.80
Anthracite.....	6.50	13.00	19.50	26.00	32.50	39.00	45.50	52.00	58.50	65.00
Illinois.....	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00
Do.....	10.93	21.86	32.79	43.72	54.65	65.58	76.51	87.44	98.37	109.30
VERTICAL BOILER.										
Coke.....	7.19	14.38	21.57	28.76	35.95	43.14	50.33	57.52	64.71	71.90
Pocahontas.....	7.30	14.60	21.90	28.20	36.50	43.80	51.10	58.40	65.70	73.00
Anthracite.....	7.46	14.92	22.38	29.84	37.30	44.76	52.22	59.68	67.14	74.60

Relative values of fuels (determined by evaporative tests) with price varying from \$1 to \$10 per ton of 2,000 pounds for Pocahontas coal.

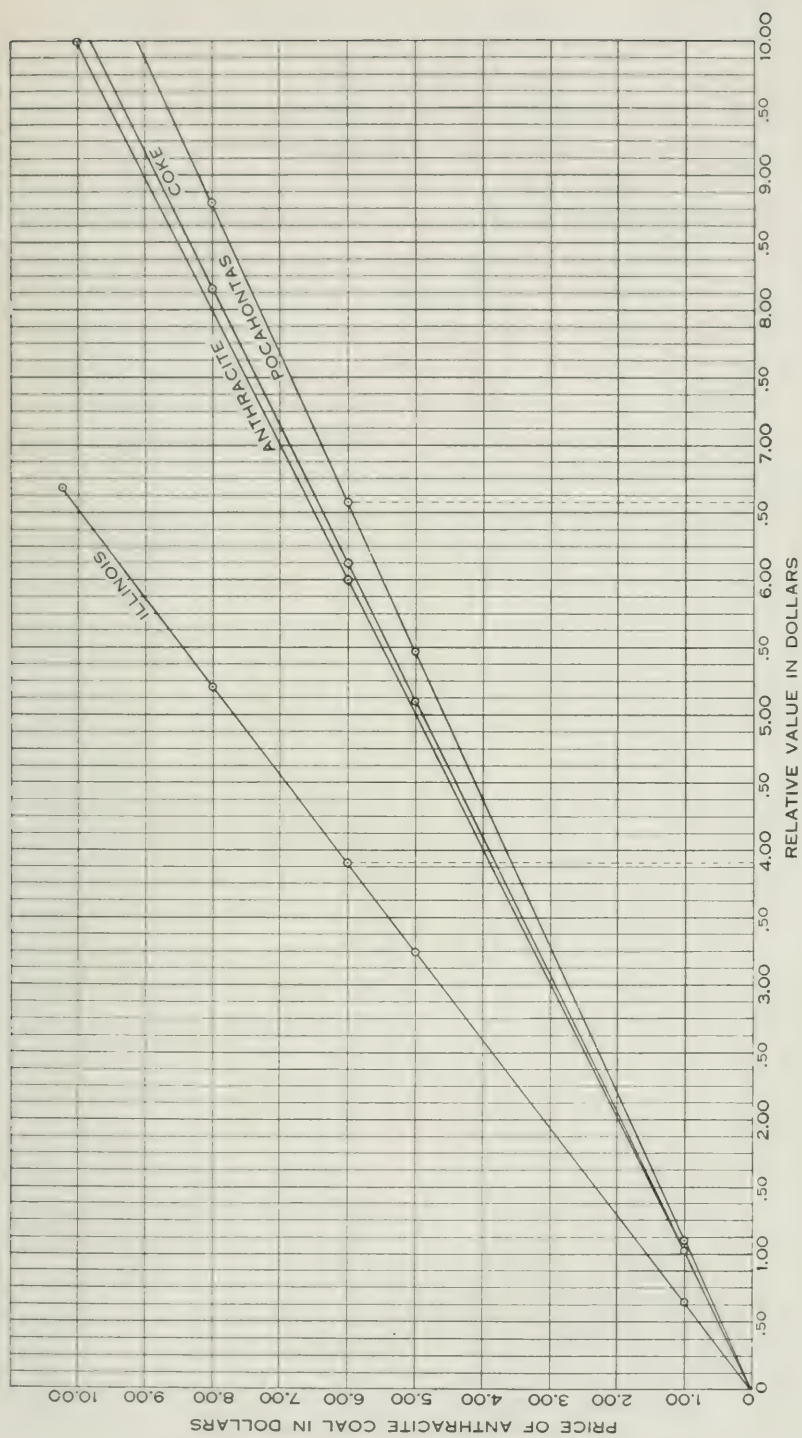
Kind of fuel.	\$1.	\$2.	\$3.	\$4.	\$5.	\$6.	\$7.	\$8.	\$9.	\$10.
SECTIONAL BOILER.										
Pocahontas.....	\$1.00	\$2.00	\$3.00	\$4.00	\$5.00	\$6.00	\$7.00	\$8.00	\$9.00	\$10.00
Maryland.....	.997	1.994	2.991	3.988	4.985	5.982	6.979	7.976	8.973	9.970
Pennsylvania.....	.961	1.922	2.883	3.844	4.805	5.766	6.727	7.688	8.649	9.610
Do.....	.947	1.894	2.841	3.788	4.735	5.682	6.629	7.576	8.523	9.470
Coke.....	.928	1.856	2.784	3.712	4.640	5.568	6.496	7.424	8.352	9.280
Anthracite.....	.911	1.822	2.733	3.644	4.555	5.466	6.377	7.288	8.199	9.110
Illinois.....	.592	1.184	1.776	2.368	2.960	3.552	4.144	4.736	5.328	5.920
Do.....	.542	1.084	1.626	2.168	2.710	3.252	3.794	4.336	4.878	5.420
VERTICAL BOILER.										
Coke.....	.985	1.970	2.955	3.940	4.925	5.910	6.895	7.880	8.865	9.850
Pocahontas.....	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Anthracite.....	1.022	2.044	3.066	4.088	5.110	6.132	7.154	8.176	9.198	10.220

A part of this table is figured on the cost of evaporating 1,000 pounds of water. Different fuels may be compared on this basis; for example, at a locality where anthracite costs \$8 a ton and coke \$6, the cost of evaporating 1,000 pounds of water with anthracite in a sectional boiler would be 52 cents and with coke 38.28 cents. This means that at such a locality the same amount of work could be accomplished at a saving of about \$2 a ton by using coke instead of anthracite. Similar comparisons of other fuels may be made from this table.

The last part of this table offers another method for determining the comparative values of fuel at any given locality. For instance, if at a certain place Pocahontas coal costs \$5 a ton, anthracite is actually worth \$4.56, coke \$4.64, good Illinois coal \$2.96, and Pennsylvania coal \$4.80. If anthracite sells at this same place for \$8, it is a luxury by \$3.44 a ton over Pocahontas, which, on the other hand, may not be the cheapest available fuel in that market. If good Pennsylvania coal can be purchased for \$3.50 a ton, or good Illinois coal for \$2.50, they offer a saving of \$1.30 and \$0.46, respectively, over the cost of Pocahontas at this particular locality. The relatively higher price of anthracite may be offset in public opinion by the fact that the coal is cleaner and burns without smoke.

At another place, should anthracite cost \$8.20 a ton, Pocahontas coal would be worth \$9 a ton, good Pennsylvania coal \$8.65, coke \$8.35, and good Illinois coal \$5.33. If any of the four last-named fuels cost less than the amounts stated, they would be just that much cheaper than anthracite coal.

A more convenient way of determining the comparative cheapness of different fuels is by means of a diagram like that forming Pl. III, in which the cost of anthracite coal is taken as a standard and the values of three other fuels based on the results of tests are referred to it. Suppose a man wishes to know the relative values of Illinois and Pocahontas coals in a locality where anthracite can be had for \$5 per ton. Placing a straightedge on the \$5 horizontal line, he notes the point of intersection with the line showing the value of Illinois coal and the point at which a perpendicular from this point of intersection strikes the base and finds that with anthracite at \$5 a good Illinois coal is worth \$3.25. In the same way he finds that Pocahontas coal is worth \$5.47. At another locality, where anthracite can be had for \$6, Illinois coal, as shown by the diagram, is worth \$3.90, Pocahontas coal \$6.58, and coke \$6.12.



RELATIVE VALUE OF FUELS FOR HOUSE-HEATING BOILERS.

SUMMARY OF RESULTS.

The briquets and coal burned in the tests at St. Louis came from eleven States and Territories. There were 58 tests—11 on raw coals, 34 on round briquets, and 13 on square briquets. Most of the tests were run for about eight hours at an average steam pressure of 2 to 3 pounds. The charge of fuel at each firing ranged from 55 to 175 pounds. The interval between firings varied considerably; in some tests coal was fired every half hour and in others every two hours. The average efficiency in all the tests was 51.48 per cent; it ranged from 38.67 per cent on an Illinois coal to 65.36 per cent on a Virginia coal. The average percentage of builder's rated capacity developed was 59.2; it ranged from 44 per cent on an Illinois coal to 77.2 per cent on an Indian Territory coal. The lowest boiler horsepower developed was 12.1 and the highest 20.6. With the cost of fuel assumed at \$1 per 2,000 pounds, the cost of evaporating 1,000 pounds of water from and at 212° F. ranged from 5.56 cents for a briquetted Pennsylvania coal to 11.93 cents for a briquetted Illinois coal. Most of the briquets, whether made from eastern or western coal, smoked badly for several minutes after firing. Of the coals tested raw, six were western and five eastern. The high-volatile western coals smoked badly, but the eastern coals made comparatively little smoke.

An average capacity of 65 per cent was carried on all the 24 briquet tests at Urbana, the range being from 53.2 to 71.4 per cent. To carry only 65 per cent of the rated radiating surface, the draft through the fire was wholly or very nearly cut off for half to three-quarters of the time. The boiler horsepower developed on boiler A ranged from 4.52 to 4.96 and on boiler B from 4.97 to 6.16. The average efficiency of the boiler and furnace, figured on a dry-coal basis, was 44.85 per cent for the 24 tests. A comparison of eight tests on briquets, of which four were made on large briquets and four on small briquets, shows that the large briquets invariably gave an appreciably higher efficiency, indicating that the size of the coal burned is an important factor. With the cost of fuel assumed at \$1 per 2,000 pounds, the cost of evaporating 1,000 pounds of water from and at 212° F. ranged from 6.74 cents on a Pennsylvania briquet test to 12.47 cents on an Illinois test. The briquets started readily from a wood fire and burned well, but owing to the difficulty of obtaining complete combustion, the average efficiency from an eight-hour test was low. The formation of soot in the flues of boiler B was more troublesome and affected the economy more than in boiler A. So much soot was formed from partial combustion of the briquets in both boilers that the flues were blown after every test. In two tests the flues of boiler B were completely stopped up at the end of the eight-hour run.

CONCLUSIONS.

On comparing the results of tests on the coal and briquets there seems to be no advantage in the briquets over coal of a suitable size for house-heating boilers. Briquetting a good bituminous coal would be justified only when slack is used for material and the gain from briquetting would lie almost entirely in the more favorable size of the fuel. This gain would be less for coals that coke readily than for noncoking coals or for coking coals that are not suitable for domestic purposes in the form of slack. Briquets made from such coal burn fairly well, as they allow the air to pass up through the fuel bed.

The experiments showed that the pitch binders used are not suitable for a furnace working at the low temperatures common in a house-heating boiler, as they volatilized and in most cases escaped unburned or were deposited on the surface of the boiler. In the St. Louis tests this coating burned off once or twice a day, causing a high temperature in the flue and, as a consequence, danger from fire. There was a similar deposit of tarry matter on the boilers at Urbana, but it did not ignite, probably because owing to the more perfect control of the conditions the fire did not get hot enough. This deposit reduced the efficiency of the boiler. Briquets with binders that do not volatilize so readily would probably show superior results.

The briquets tested gave off much smoke, owing to the nature of the material used as a binder, and for this reason also such briquets are unsuited for domestic use.

The results of these tests indicate that coals containing the higher percentages of fixed carbon give the least smoke and the best results for economy.

COST OF HEAT FROM CENTRAL PLANTS.

In the course of an investigation into the causes that contribute to the smoke nuisance of cities, outlined in Bulletin 334, inquiries were sent to all the known commercial steam or hot-water heating plants of the United States. This was done because the substitution of large units equipped for burning coal in the most economical manner in the place of small units of less efficient design offers one way of reducing the total quantity of smoke given off in burning a certain amount of coal and in addition is a possible factor in conserving the nation's fuel supplies. Inquiries were sent to 150 plants and replies were received from 57. The information gathered from these replies is to be published in detail in a bulletin now in preparation. Of the plants that answered 41 gave figures showing the price of heat to the consumer either per square foot of radiating surface or per 1,000

pounds of condensed steam. The figures are presented in the following table:

TABLE 17.—*Price of heat from central heating plants.*

State.	Steam.		Hot water.		State.	Steam.		Hot water.	
	Per square foot.	Per 1,000 pounds.	Per square foot.			Per square foot.	Per 1,000 pounds.	Per square foot.	
	<i>Cents.</i>	<i>Cents.</i>	<i>Cents.</i>			<i>Cents.</i>	<i>Cents.</i>	<i>Cents.</i>	
Colorado.....	65			Missouri.....				25	
Illinois.....	24			Montana.....	60				
Do.....		45		New York.....		50			
Do.....	25			Do.....		50			
Do.....	28			Do.....		42.5			
Do.....	25		15	Do.....		48			
Do.....	22.5		17.5	North Dakota.....		60			
Do.....			15	Do.....		40			
Do.....			20	Ohio.....				15	
Indiana.....			20	Do.....				15	
Do.....			18	Do.....				20	
Do.....			15.5	Do.....				17.5	
Do.....			12.5	Do.....		50			
Do.....			15	Pennsylvania.....	25				
Do.....			17	Do.....		40			
Iowa.....			18	Do.....	34				
Do.....			20	Do.....	33.3				
Do.....			15	Rhode Island.....			66		
Do.....		50		Wisconsin.....				25	
Minnesota.....		60		Do.....				25	
Missouri.....		56							

On a comparison of the figures showing the rate per 1,000 pounds of condensed steam with those of cost for evaporating 1,000 pounds of water given in Table 16 (p. 39), it becomes evident that considering all the factors concerned in the production of heat on the premises, such as cost of plant, depreciation, repairs, cost of fuel and labor, and the elimination of all discomfort from dust, ashes, or smoke, the householder is fortunate who can purchase heat from a central station at a reasonable price.

PUBLICATIONS ON FUEL TESTING.

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director, Bureau of Mines, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE BUREAU OF MINES.

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Oviitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp.

BULLETIN 5. Washing and coking tests of coal at the fuel-testing plant, Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

BULLETIN 7. Essential factor in the formation of producer gas, by J. K. Clements, L. H. Adams, and C. N. Haskins. 1911. 58 pp.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp.

BULLETIN 9. Recent development of the producer-gas plant in the United States, by R. H. Fernald. 1909. 82 pp., 2 pls. Reprint of United States Geological Survey Bulletin 416.

BULLETIN 11. The purchase of coal by the Government under specifications, by G. S. Pope. 1911. 80 pp. Reprint of United States Geological Survey Bulletin 328.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp.

BULLETIN 14. Briquetting tests of lignite at Pittsburg, Pa., 1908-9, by C. L. Wright. 1911. 58 pp. 11 pls.

BULLETIN 21. The significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 62 pp. Reprint of United States Geological Survey Bulletin 367.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp. Reprint of United States Geological Survey Bulletin 343.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. \$1.50.

BULLETIN 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

BULLETIN 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp. 20 cents.

BULLETIN 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp. 25 cents.

BULLETIN 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 cents.

BULLETIN 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 4 pls.

BULLETIN 363. Comparative tests of run-of-mine and briquetted coal on locomotives, by W. F. M. Goss. 1908. 57 pp.

BULLETIN 373. The smokeless combustion of coal in boiler plants, by D. T. Randall and H. W. Weeks. 1909. 188 pp. 20 cents.

BULLETIN 402. The utilization of fuel in locomotive practice, by W. F. M. Goss. 1909. 28 pp.

